Publication 875 December, 1952

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Published by

Department of Agriculture, Ottawa, Canada
In Co-operation with the Ontario Department of Lands and Forests

3M—16546—12:52

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1953

The Relation of Mortality of Balsam Fir, Abies balsamea (L.) Mill., Caused by the Spruce Budworm, Choristoneura fumiferana (Clem.), to Forest Composition in the Algoma Forest of Ontario*

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*A condensation and revision of a thesis submitted to the University of Toronto in November, 1950, in partial fulfilment of the requirements for the degree of Master of the Science of Forestry.

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CONTENTS

ABSTRACT

The Algoma forest is briefly described, as well as the history of the recent spruce budworm epidemic. Sampling, by the continuous-tally strip method, was carried out in portions of six watersheds.

The analysis, which consisted of two principal parts, was restricted to localities where the over-all mortality of balsam fir was moderately high (about 75 per cent). The first part dealt with the effect on fir mortality of individual variables, namely, total age of fir, topographic site, basal area per acre of fir, percentage content and relative height or crown class of fir, basal area of white spruce and basal area per acre of the whole stand. The basal area of fir appeared important, in that percentage mortality of fir usually increased with fir content. In most cases, fir mortality increased with relative height of fir.

In the second part of the analysis, where important variables were held under control, it was found that greatest mortality of fir occurred in cover types where the softwood content was primarily fir-spruce or pine. Damage to fir was less where the softwood content was mainly cedar or a mixture of species. The influence on fir mortality of increasing proportions of hardwood was variable, depending on the relative height of the fir. Where the fir was in the intermediate height class, fir mortality decreased with increasing proportions of hardwood; where understory, fir mortality tended to increase with increasing proportions of hardwood, and where co-dominant, fir mortality was not affected to any extent by proportion of hardwood.

INTRODUCTION

During the past three decades there has been a succession of outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clem.), in various parts of Ontario. The outbreaks still continue and to date have covered most of the susceptible forests of the province, killing large quantities of balsam fir*. White spruce has also suffered extensive mortality.

The occurrence of spruce budworm epidemics is not a new phenomenon, for destructive outbreaks in Eastern Canada and the northeastern United States have been recorded since early in the 1800's (27). Outbreaks in eastern North America have been observed and followed fairly closely since about 1909 (16, 31). Recent evidence suggests that outbreaks occurred in Ontario during the 19th century, and it is probably that there have been budworm outbreaks ever since balsam fir has been an important constituent of the forest.

In all likelihood balsam fir has, since glacial times, played a prominent role in the species composition of eastern Canadian forests. This condition resulted from two factors: balsam fir was one of the first forest invaders after the last glaciation (18), and its continued importance was insured by its tolerant characteristics and its prolific regenerative qualities.

Since budworm outbreaks arise in different areas and cause varying degrees of damage, the present investigation was made to determine the relation between degree of balsam fir mortality and characteristics of the forest. Thus the significance of the problem is the possibility of being able to recognize danger- or hazard-areas before they are actually damaged by the insect. If this can be accomplished, losses can be reduced by pre-salvage operations, and then through forest management an attempt may be made to reduce the probability of recurring damage.

The first intensive investigations of the problem were carried out by Craighead (7). In the area throughout southwestern Quebec and New Brunswick affected by the outbreaks of 1909-1924, he studied the extent of damage to fir, white spruce and black spruce in each of several broad forest types, five of which have counterparts in Algoma. He also summarized the contemporary recommendations for management to produce a more budworm-proof forest. In a later paper, Craighead (8) found that the degree of mortality suffered by spruce-fir stands was correlated with their rate of growth prior to attack. Trees with the greatest annual increment suffered the least mortality.

Graham and Orr (14), studying the effects of the 1912-18 outbreak in Minnesota, also related damage of fir and spruce to forest types. Mortality of spruce was highly variable, and was considered generally to result from indirect effects of the budworm epidemic.

Based on observations of the recent outbreaks in Ontario and Quebec, Westveld (36) developed a formula for evaluating the vulnerability of any stand. This evaluation depended on the size and content of fir in a stand, and did not take species composition into account. The formula was designed primarily for the recognition of hazard-areas in the budworm-threatened pulpwood forests of the northeastern United States.

In New Brunswick, Balch (3) considered susceptibility of a forest to the budworm to be closely associated with the volume of balsam fir and spruce

* Appendix A contains a list of the scientific names of all tree species referred to in the text, together with the symbols used for them in tables and figures.

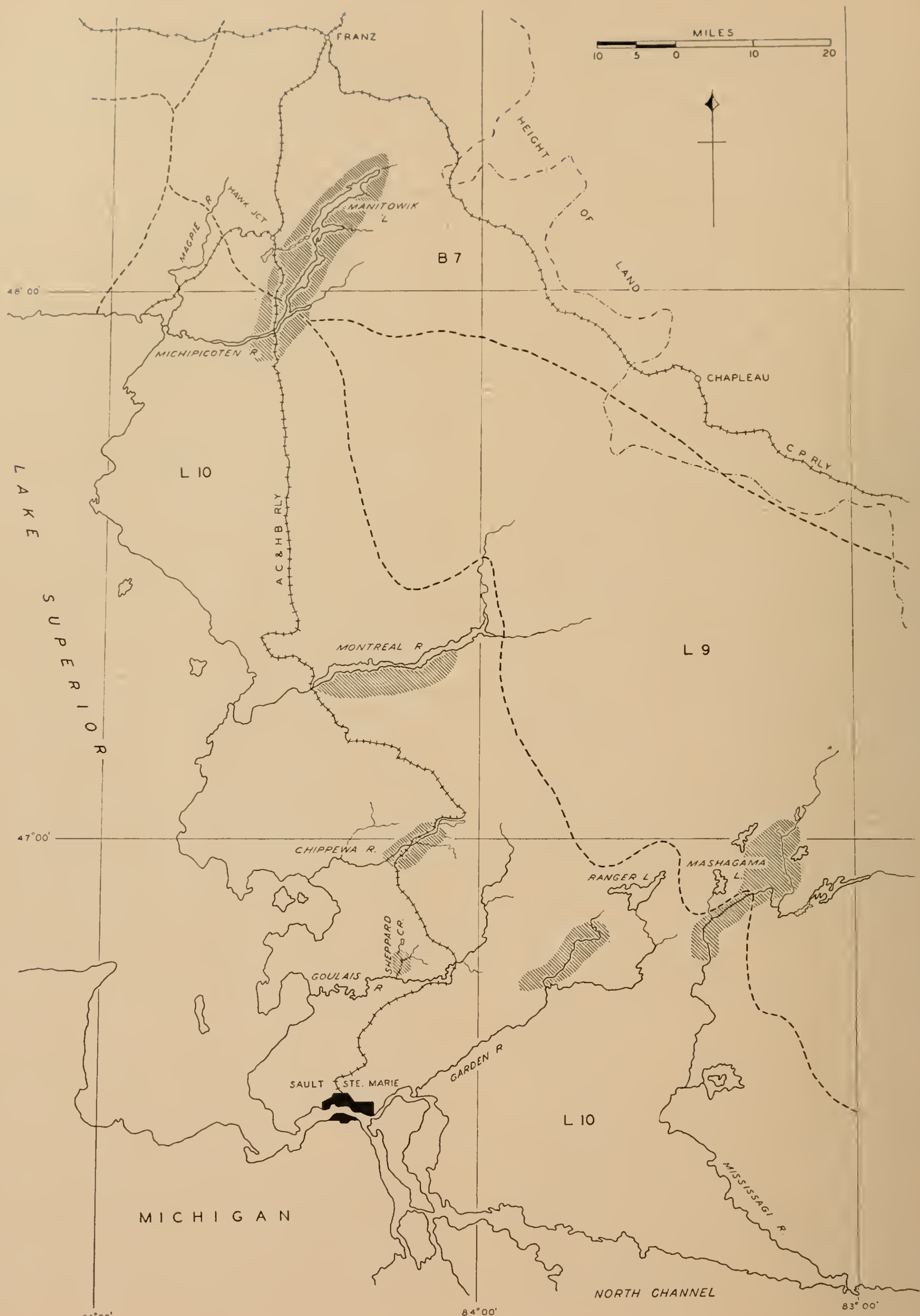


Fig. 1.—Map showing the Algoma area in part. Hatched portions are localities sampled in present survey. Halliday's classification of the forest is also indicated; Timagami Section (L 9), Algoma Section (L 10), Central Transition Section (B 7).

per acre, the percentage of fir in the stand and its age. Using these criteria and aerial photographs to delineate hazard zones, a susceptibility map was drawn up for the province.

McLintock (22) reduced the evaluation of budworm hazard to a single-tree basis. Increased vigour of spruce and fir, as evidenced by good crown development, was thought to reduce the risk of mortality from severe defoliation.

The results of the protracted infestation in Ontario left some doubts as to whether earlier concepts provided a true picture of forest conditions conducive to budworm outbreaks and serious damage in this province. Because of the extensive outbreak and the variability in fir mortality and forest types in the Algoma area* of Ontario, the forests of this area presented an unusual opportunity for attempting to discover important relations between forest conditions and severity of damage. For this reason, the area has been referred to as a "strategic area" (1). To be fully effective, the project had to be carried out where the outbreak had run its course.

The collection of data in the field extended over the summers of 1946 and 1947 and was confined to the Algoma area. Almost all the compilation, analysis and preparation of this contribution was completed while the author was stationed at the Forest Insect Laboratory, Sault Ste. Marie, Ontario.

The investigation was initiated at the joint suggestion of Dr. C. E. Atwood, Department of Zoology, University of Toronto, Dr. M. L. Prebble, Division of Forest Biology, Department of Agriculture, Canada, and Mr. J. A. Brodie, Department of Lands and Forests, Ontario, and was a co-operative project of the Department of Lands and Forests and the Department of Agriculture.

THE ALGOMA FOREST

General Description

Marked variations in topography, soil, and climate throughout the Algoma area result in a variety of forest types. The extreme southern part is characterized by the northern fringe of the Deciduous Forest Formation, made up largely of the northern hardwoods (mainly sugar maple and yellow birch); and the northern part by the Boreal Forest where the main species are black spruce, white spruce, balsam fir, aspen, and white birch. Between Sault Ste. Marie and Franz the ranges of the northern and southern species overlap. Therefore, mixed stands occur extensively, and are often composed of a great many combinations of species. As one approaches Lake Superior from the east, the northern limit of the northern hardwoods is deflected northward. In the past, the central and southern areas were marked by considerable quantities of white and red pine but, through cutting, these stands have been reduced to small segments, chiefly confined to presently inaccessible localities.

The Algoma area lies entirely within the Lake Forest as mapped by Weaver and Clements (33). According to Halliday (17), Algoma lies within two major forest regions: the Great Lakes-St. Lawrence and the Boreal Forest Regions. In Algoma, the Great Lakes-St. Lawrence Forest Region is represented by two sections (the Algoma and Timagami Sections), and the Boreal Forest by three sections. However, only one of the latter sections (the Central Transition Section) includes any of the area sampled. The three sections encountered are outlined in Fig. 1.

The present study within Algoma was concentrated in specific localities which represent a variety of conditions as to forest type, budworm history, and

* For purposes of the present report, the Algoma area is defined as the portion of Ontario shown in Fig. 1.

damage. These localities represent portions of six different watersheds, namely the Mississagi, Garden, Goulais (Sheppard Creek), Chippewa, and Montreal Rivers, and the Michipicoten River—Manitowik Lake drainage. Sampling was carried out in the townships listed below.

General Locality	*Location of Sampling by Townships*
Mississagi River	2E; 3E; 4E; 5E; 4D; 5D
Ranger Lake (Garden R.)	Whitman; Curtis; 22, Ra. X; 3H
Sheppard Creek	Shields; Deroche
Chippewa River	25, Ra. XII
Montreal River	Home; 26, Ra. XV and Ra. XVI; 24 and 25, Ra. XVI
Michipicoten River	28, Ra. XXII; 28, Ra. XXIII
Manitowik Lake	27, Ra. XXIV; 26 and 27, Ra. XXV 25 and 26, Ra. XXVI

The southern part of the area studied in the Mississagi watershed is within the Algoma Section of the Great Lakes-St. Lawrence Region, while the northern part, commencing about the lower part of Twp. 4E, falls within the Timagami Section. Since the area sampled lies mainly in the transition belt between the two sections, there is no pronounced difference in cover type between the southern and northern parts, except for the more frequent occurrence of sugar maple and yellow birch in the southern portions.

The Garden River area was sampled along the Ranger Lake Road, and is referred to in the text as the Ranger Lake area. The area is well within the Algoma Section of the Great Lakes-St. Lawrence Region.

The Sheppard Creek valley is a part of the Goulais River drainage, and is within the Algoma Section of the Great Lakes-St. Lawrence Forest Region; fir and spruce grow in the valley and the cover type gradates into yellow birch and sugar maple on the slopes and ridge tops. From the standpoint of its fir and spruce content, the valley has a distinctly isolated appearance when viewed from the air. From aerial photographs the area of softwood (fir-spruce) forest was calculated to be 1,500 acres, and of adjacent mixedwood, 2,500 acres. Extensive hardwood stands surround the mixedwood stands. A striking feature is the comparative richness of the site as evidenced by some balsam firs up to 20 inches D.B.H. No specimens of fir over 115 years old were encountered.

In many respects the Chippewa River forest resembles the Sheppard Creek forest. It also is located within the Algoma Section of the Great Lakes-St. Lawrence Forest Region. The valley bottom of the sample area has quite a high concentration of fir and spruce, and this type is continuous over 3,200 acres. Coniferous swamp and bog types of limited extent are frequently encountered. Mixedwood types adjacent to the fir-spruce types cover 8,100 acres. Beyond this the forest is predominantly hardwood.

The Montreal River forest is quite typical of the Algoma Section of the Great Lakes-St. Lawrence Region. Sugar maple and yellow birch are the predominant species on the northern slopes; white birch, white spruce, balsam fir, and white pine are the chief species on the southern exposures. These latter species are also the main species in the eastern part of the sample area. Swamp conditions are comparatively rare. Although sugar maple is the predominant species on upper northern slopes, and forms the climax type over much of the area, it is close to its northern limit, and does not reach good commercial development.

Although the Michipicoten River area is within the boundaries of the Algoma Section of the Great Lakes-St. Lawrence Region, it is very close to the Timagami Section of the same Region, and to the Central Transition Section

of the Boreal Forest. As might be expected from its location in relation to Halliday's broad types, there is a great variety of cover types. Sugar maple and yellow birch are quite scarce, although plentiful enough in pockets on ridge tops to characterize local cover types. In the immediate past, stands of white and red pine, and of jack pine occupied much of the area. Only remnants of these stands remain, having been replaced mostly by stands of balsam fir, white birch, aspen, and white spruce.

The Manitowik Lake area is within the Central Transition Section of the Boreal Forest, although very close to the Algoma and Timagami Sections of the Great Lakes-St. Lawrence Region. No specimens of sugar maple or yellow birch were encountered in the 9·5 miles of representative strip tally. Red maple occurred infrequently, and generally was not over 5 inches D.B.H. Since the Manitowik area is well south in the section, the cover type is slightly atypical of the section as a whole, in that white spruce and aspen have more than a scattered distribution.

Fire and Cutting History

Records maintained by the Division of Forest Protection, Ontario Department of Lands and Forests, show that lightning is prevalent in the area under study and, except in swamps and in areas where hard maple and yellow birch predominate, fire has played a major role in the development of many stands.

On the whole, Algoma has been seriously depleted of much of its commercial coniferous timber through cutting operations. The lumber industry has been centred mainly in the south, and pulpwood operations chiefly in the more northerly areas, principally the Boreal Forest Region.

Mississagi River.—Large fires (29) over much of the upper Mississagi area about 1780, as well as earlier, gave rise to many of the present pine stands; ages taken on white, red, and jack pine in 1946 were all from 160 to 165 years. Smaller local fires have occurred from time to time and several fire stands were encountered in the survey with stand ages ranging between 45 and 70 years. Such stands are, as a rule, confined to small areas of not more than a few hundred acres.

Logging was centred in the middle and upper portions of the Mississagi watershed (starting in Twp. 2F) in the late 1920's, and extensive operations have continued to the present. No pulpwood had ever been cut in the upper portion of the Mississagi River drainage prior to the present survey.

Ranger Lake.—The area sampled appears to have been little affected by recent fire, as evidence of only two or three fires was noticed. Those fires which occurred appear to have accompanied logging operations.

Logging has had a considerable influence on stand development and indeed, many of the present fir-spruce stands have come after removal of white-pine stands (Fig. 27). Although there is no record of logging for white pine and white spruce in the sampled area prior to 1903, evidence of pine cutting and a marked increase in diameter increment on nearby fir and spruce in the vicinity of the Little Garden River indicate that some cutting was done as early as 1900. The early operations were confined to Whitman and Curtis Townships. In the intervening period, small cuts of pulpwood have occasionally been made. Because the larger areas of pine were logged early in the century and have since been occupied by other species, and because more recent cuts have been small and scattered, the forest on the whole does not have a disturbed appearance.

Sheppard Creek.—The Sheppard Creek area has been undisturbed by recent fire. The valley was cut over for pulpwood about 1904, and much of the present

balsam fir and spruce dates from about that time. White spruce was the chief species cut, and it appears that the proportion of fir has greatly increased in the succeeding forest. There has been no subsequent disturbance.

Chippewa River.—None of the stands encountered revealed a fire history within the last 200 to 300 years. Most of the area was cut over from about 1903 to 1915, principally for pine and spruce, and since very little balsam fir has ever been taken out, there is a considerable accumulation of this species. This accounts for the large proportion of over-mature fir trees (Figs. 30 and 31), many of which have been windthrown or have died of old age.

Montreal River.—The sampled portion of the Montreal River, except for the upper (eastern) area, has been undisturbed by fire and cutting for at least 300 to 400 years, which is the age of the oldest yellow birch and white cedar. Total age of balsam fir in these stands ranges from 40 to 150 years for trees 3 inches D.B.H. and up, with the main age class between 70 and 120 years. Fires have occurred in the eastern portion of the area, and some fire stands of white pine were about 160 years of age in 1946, corresponding to the main age-class of the upper Mississagi River.

Michipicoten River.—Unlike the areas previously described, this area has been completely burned over once, and some parts twice, within recent times. Fire scars on pine indicate fires, at different periods, as far back as 1790. There are scattered evidences of light white pine cutting about 1892. This was probably associated with the early mining activity which started in the Michipicoten River area in the 1880's. Jack pine was cut as early as 1904-05 in the sampled area, and between 1910 and 1924 considerable quantities of this species were logged along the railway for piling and ties. In many cases these cut-over jack-pine stands were followed by balsam-fir stands (Fig. 33). Pulpwood cutting in the area sampled has been very light.

Manitowik Lake.—Practically the whole area sampled has been burned over at least once within recent times. Two fires (1875 and 1891) correspond to periods of human activity—construction of a tote route to the Canadian Pacific Railway in the 1870's, and pine logging. Other fire scars at various points in the area indicate fires in 1828, 1845, 1858, 1878 and 1901. Many of the stands have a decadent, even-aged overstory of aspen and white birch. These trees were about 140 years old in 1947, indicating a fire origin about 1807. Recent cutting has been confined to pulpwood operations, and these were carried out at two distinct periods. The first period of cutting around Manitowik Lake was from 1924 to 1930, when white and black spruce were the only species taken. In the three cutting seasons 1936-39, balsam fir was also included in pulpwood cuts, and some of the areas cut over for spruce about a decade previously, were re-visited and the fir taken.

History of Recent Infestation and Description of Damage

A general description of the budworm outbreak and early damage has been reconstructed from several sources. An examination of the records of the Forest Insect Survey, Canada, Department of Agriculture, for the years 1936 to 1940, has provided a fairly complete picture of the probable course of the epidemic. Special reports by Watson (32), Morley (25), and Atwood and Gray (2) present a vivid picture of the intensity and destructive nature of the outbreak in the Mississagi area. Interviews with various individuals who first noticed the infestation in certain localities have helped to make the picture more complete. The annual rings of surviving fir and spruce trees were also examined in an attempt to provide additional information on the time of infestation in the area. The results are summarized for each locality in Table 1.

TABLE 1

Summary of Infestation History for Each Locality Sampled in Algoma as Indicated by Annual Rings, Official Records, and Observations. Damage is Described in Board Terms

Locality	Sp.	n[1]	Part of Tree	Year of First Reduction	Yr. of most Intensive Reduction	Remarks
Mississagi River	Fb	45 61	Top Basal	1936, 1937[2] 1937	1942 1942	*Infestation:* Only occasional Fb and Sw trees had top radial growth first reduced in 1935. The year 1937 was the first of reduced growth at top almost as frequently as 1936. Fb and Sw appeared to have been under attack the same length of time. Infestation discovered in 1936, at which time the trees were badly defoliated (browning). Extensive mortality of Fb started by 1938.
	Sw	36 41	Top Basal	1936, 1937 1937	1942 1942	
	Sb	26 30	Top Basal	1937 1937, 1938	1942 1942	*Damage:* Almost all fir trees down to 1-, 2-, and 3-inch diameter classes were dead, especially in softwood types (Table 2 and Figs. 24, 25). Average percentage mortality of fir and white spruce by basal area at breast height, including all cover types, was 90 and 60 respectively.
Ranger Lake	Fb	40 40	Top Basal	1940, 1941 1942	1941, 1942 1945	*Infestation:* Slight indication of reduced growth in 1939 on a few Fb tops from upper (NE.) part of sample area. Collections of budworm started in 1937 (Twp. 3H). Budworm larvae plentiful in 1939. Infestation lagged somewhat in Curtis and Whitman townships. *Damage:* The area represents a transition zone of budworm damage, where mortality of fir decreased in a westerly direction, even though the fir content remained relatively high within the area of the survey (Figs. 2, 26, 27, 28). Thus the average percentage mortality of fir and white spruce by basal area for the locality, viz. 35 and 19 respectively, lost much of its meaning in view of the great range from only normal mortality in the west to almost complete mortality in the northeast.
Sheppard Creek	Fb	25 25	Top Basal	1940, 1941 1942	1941 1943, 1945	*Infestation:* No budworm collections. Infestation heavy 1939-1941. 1941 appeared to be year of heaviest attack when the trees, as observed from the air, were severely browned (C. E. Atwood). Infestation not persistent.
	Sw	12 12	Top Basal	1941 1942	1941 1943	*Damage:* Except in two or three small local pockets, in fir-spruce types, no mortality could be definitely attributed to the budworm (Table 2). The average percentage mortality of fir and white spruce by basal area including all types was 19 and 14 respectively.
Chippewa River	Fb	48 56	Top Basal	1940, 1941 1941, 1942	1941 1943	*Infestation:* No budworm collections. Infestation heavy 1939-41. 1941 appeared to be year of heaviest attack when the trees, as observed from the air, were severely browned (C. E. Atwood). Infestation not persistent.
	Sw	6 7	Top Basal	1941 1942	— 1943	*Damage:* Although the infestation appeared to have been uniformly heavy, the resultant tree mortality was small (Figs. 30, 31). The average mortality of fir and white spruce over the area was 26 per cent in each case.
Montreal River	Fb	37 37	Top Basal	1940, 1941 1942	— 1945	*Infestation:* Budworm larvae reported plentiful on Fb and Sw in Twps. 8G, 8H in 1939. No reported observations in the immediate vicinity of Montreal River.
	Sw	7 7	Top Basal	1941 1942	— 1945	*Damage:* The average percentage mortality by basal area of fir and white spruce was 69 and 42 respectively. However, these figures do not accurately portray the conditions since the mortality was very high in the eastern part of the sample area (about 80 per cent for fir), and gradually became less towards the west (Fig. 2).
Michipicoten River	Fb	19 19	Top Basal	1940, 1941 1943	— 1945	*Infestation:* Some spruce budworm and numerous *Acleris variana* (Fern.) collected from Sw near Wawa in 1938. No infestation reported until 1940.
	Sw	10	Basal	1943	1945	*Damage:* Damage was heavy over the area sampled (Fig. 32). Average percentage mortality of fir and white spruce by basal area was 78 and 26 respectively.
Manitowik Lake	Fb	13 14	Top Basal	1941, 1942 1943	— 1945	*Infestation:* A few budworm larvae were first collected in 1939 at Hawk Junction. In 1940 Fb was reported to be dying in Magpie Valley (McCormack Lake). Manitowik area seemed to have lagged behind (see text).
	Sw	15	Basal	1943	1945, 1946	*Damage:* Damage was heavy over the area sampled (Fig. 34). Average percentage mortality of fir and white spruce by basal area including all types, was 70 and 33 respectively.

[1] Number of trees examined (in some localities, top portions were not obtained from all sample trees).
[2] Where two years are quoted, either one or the other indicates the phenomenon under consideration; underlining denotes the year most commonly encountered.

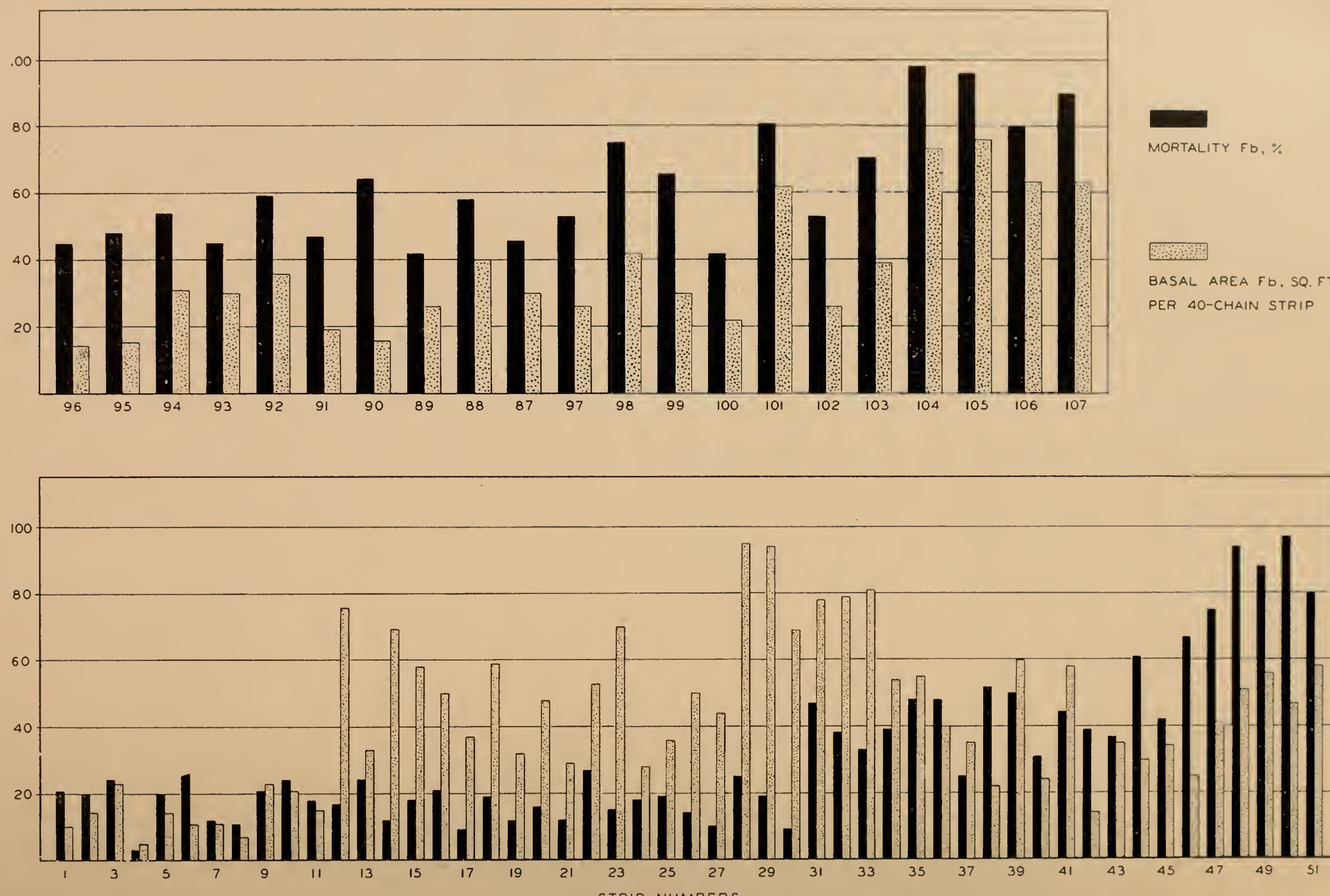


Fig. 2.—Upper: Percentage mortality of balsam fir per 40-chain strip, compared with the basal area of fir per strip, Montreal River area, for all cruise strips in sequence from west to east. Lower: As above, but for Ranger Lake area.

Outbreaks of the spruce budworm in Ontario have been recorded since 1912 (12, 16, 31). The Algoma outbreak was discovered at Mashagama Lake, Mississagi River area, in 1936. At that time "tree browning", indicating heavy feeding, was evident and it therefore appears that the budworm population started to build up in the very early 1930's. Mortality of balsam fir had commenced by 1938.

Although there were no large areas of open fir and spruce in the Mississagi area because of the predominance of pines and hardwoods, extensive pine cutting in Townships 3D, 4D, 3E, 4E, 3F and 4F since the late 1920's may have materially aided in initiating and intensifying the infestation. The fir in general grew as an understory to pine and also was quite old (80 to 100 years as of 1930). Upon release, the balsam-fir trees probably became heavy flower producers and in this condition would be conducive to budworm population build-up (5).

It appeared to early observers that the Algoma outbreak started in the Mississagi Valley and spread mainly in a northeasterly direction towards Biscotasing on the Canadian Pacific Railway, and in a northwesterly direction beyond Michipicoten. However, there is considerable evidence that spread to the north and west must have been very limited. Firstly, infestations north and south of Ranger Lake (within a few miles of the Mississagi area) reached their peaks about 3 or 4 years after the Mississagi infestation. Secondly, the uniformity in initiation of growth reduction in top disks of balsam-fir trees from the Ranger Lake, Sheppard Creek, Chippewa, Montreal, and Michipicoten River areas (Table 1) would indicate that the infestation arose more or less simultaneously over a wide area. Thirdly, the prevailing westerly winds would limit spread in a northwesterly direction. Fourthly, because fir trees were reported to be dying near McCormack Lake (in the western part of the Magpie River drainage) in 1940, even before budworm larvae were observed to be numerous around Hawk Junction, there is a strong possibility that the Magpie R. Valley, or the area to the west, was a separate focus from which the infestation spread eastward to the Manitowik Lake area.

Most of the commercially mature fir is dead from Sudbury to Lake Superior, and north to the Sudbury-Geraldton line of the Canadian National Railway. Table 2* presents a summary of fir mortality in each diameter-class group, within each locality having a generally uniform degree of fir mortality. Three of the most commonly sampled cover types are represented. The comparatively low mortality in the Sheppard Creek and Chippewa River valleys represents conditions over a very small area, whereas mortality in the remaining three localities is more typical of conditions throughout most of Algoma. Neither the Ranger Lake nor the Montreal River areas are included since mortality was very variable (Fig. 2) and a general average would be misleading.

In some areas, large percentages of white spruce are also dead, especially where this species is mixed with substantial quantities of fir. But in general, white spruce survived the infestation to a much greater extent than fir (Figs. 25, 28, 35), and except in the Mississagi area, did not suffer more than about 40 per cent mortality in softwood and mixedwood types. Mortality of black spruce is often as high as 50 per cent or more, when this species is intermixed with fir and white spruce, but is negligible when it occurs in pure stands. Large areas have been rendered useless commercially until a new crop matures even

* In the Mississagi River area, most of the living fir occurred in the 1- to 3-inch diameter classes. Since most of the fir mortality had taken place by 1940, the lapse of time between 1940 and time of making the survey (1946) was sufficient to permit a change in distribution of surviving trees in the lower diameter classes. Therefore the percentage mortality of fir in the 1-, 2-, and 3-inch classes as of 1946 would not necessarily be a true picture of the damage caused by the budworm. It remained to determine the number of trees which entered and went out of each diameter class during the intervening period.

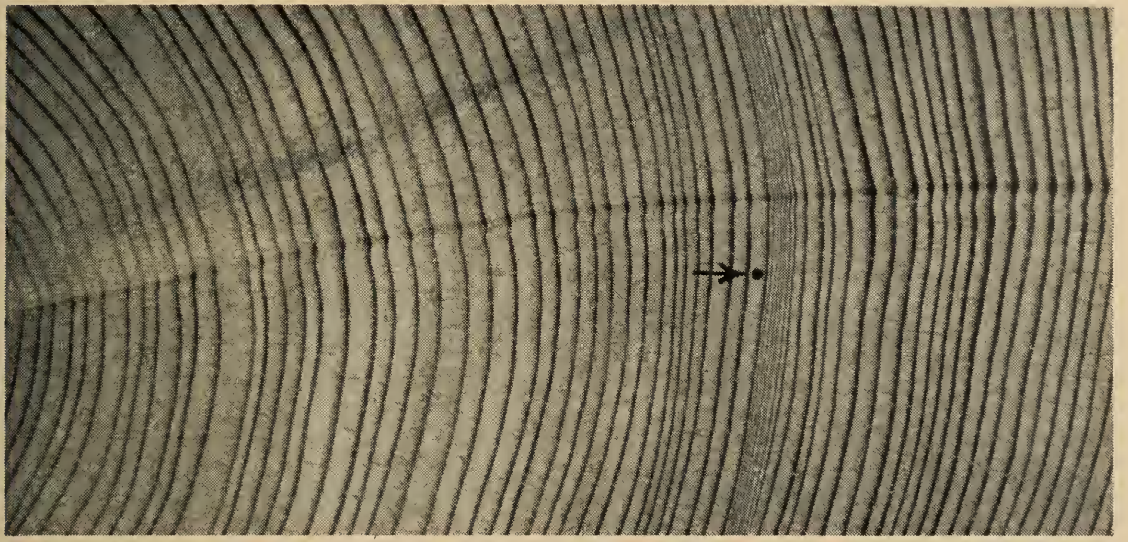
Results showed that, taking the Mississagi area as a whole, the percentage mortality of fir in the 1-, 2-, and 3-inch trees, given in Table 2, is only slightly less than that which existed at the time when the greatest rate of mortality occurred. For practical purposes, the percentage mortality remained the same. The mortality in larger diameter classes no doubt remained the same between 1940 and 1946 because diameter-growth suppression was so intense during the period that few trees had recovered sufficiently to have passed into higher diameter classes.

TABLE 2

Summary of Fir Mortality by Number of Stems per Acre in each Diameter-class Group for Three Main Cover Types in Localities where Over-all Mortality was Uniform

Locality	SFb											SHI_{FS}										HSI_{FS}									
	n[1]		1	2	3	4–6	7–9	10–12	13–18	19+	Total	n	1	2	3	4–6	7–9	10–12	13–18	19+	Total	n	1	2	3	4–6	7–9	10–12	13–18	19+	Total
Mississagi River	10	L[2]	40	9	2	—	—	—	—	—	51	12	46	27	10	7	2	—	—	—	92	10	73	71	35	26	9	—	—	—	214
		D	76	125	126	165	111	29	5	—	637		51	83	77	133	60	11	—	—	415		88	80	54	57	36	2	—	—	317
		%D	66	93	98	100	100	100	100	—	93		53	75	88	95	97	100	—	—	82		55	53	61	69	80	100	—	—	60
Sheppard Creek	13	L	42	40	45	94	64	17	2	+[3]	304	8	31	35	32	52	53	17	5	—	225	1	32	48	32	96	16	—	—	—	224
		D	44	43	29	24	9	8	3	—	160		13	10	10	1	2	1	4	—	40		—	—	—	—	—	—	—	—	—
		%D	51	52	39	20	12	32	60	0	34		30	22	24	2	4	6	44	—	15		0	0	0	0	0	—	—	—	0
Chippewa River	13	L	85	60	68	101	51	15	4	—	384	11	66	57	50	83	59	14	4	—	333	4	83	44	41	61	24	12	—	—	265
		D	26	18	17	12	31	10	2	—	116		13	5	4	7	12	5	1	—	49		4	1	3	8	15	5	+	—	36
		%D	23	23	20	11	38	40	33	—	23		16	8	7	8	17	26	20	—	13		5	2	7	12	38	29	100	—	12
Michipicoten River	13	L	126	43	36	27	9	+	—	—	241	15	56	32	42	46	16	1	—	—	193	8	48	40	38	36	11	1	—	—	174
		D	121	83	79	161	60	16	1	—	521		26	22	28	66	48	14	3	—	207		21	23	18	37	27	6	+	—	132
		%D	49	66	69	86	87	100	100	—	68		32	41	40	59	75	93	100	—	52		30	36	32	51	71	86	100	—	43
Manitowik Lake	7	L	103	57	55	31	4	—	—	—	250	16	76	43	40	42	5	+	—	—	206	23	32	30	24	45	10	1	—	—	142
		D	59	58	52	118	44	6	3	—	340		56	48	56	112	37	7	2	—	318		16	14	16	46	26	6	1	—	125
		%D	36	50	49	79	92	100	100	—	58		42	53	58	73	88	100	100	—	61		33	32	40	50	72	86	100	—	47

[1] Number of sample plots used to calculate the average distribution of fir mortality (all samples are at least 0.1 acre).
[2] Living balsam fir (L); Dead balsam fir (D).
[3] An average of less than one stem per acre.



Portions of basal disks from white spruce trees, showing some evidence of an old spruce budworm epidemic.

	Locality	D.B.H.	Est. Total Age of Tree	Yr. Marked by Dot
Fig. 3.	Chippewa R.	8 in.	170	1838
Fig. 4.	Michipicoten R.	12 in.	180	1834
Fig. 5.	Manitowik L.	10 in.	—	1834

Reduced increment resulting from the recent epidemic is seen adjacent to the bark in Fig. 5.

though the mortality of spruce may be quite low, because with the fir eliminated, the remaining stand volume is often too low for profitable pulpwood operations.

No over-all quantitative estimate of mortality was made because of the difficulty in estimating the amount of spruce and balsam fir in Algoma. Brown (6) estimated the total volume of balsam fir and spruce killed in the Algoma outbreak to be one million, one hundred thousand cords. However, this figure is based on very rough estimates of percentage mortality up to the end of 1939, and probably only represents a small portion of the final damage.

Evidence of an Old Infestation

Many of the oldest white-spruce trees in Algoma show a distinct band of suppressed annual rings beginning about 1835. This suppression resembles that caused by budworm feeding (Figs. 3, 4, 5). Several trees show 1838 as the first year of intense suppression. The narrowest ring within the band varies from 1839 to 1843, but usually occurs in 1839 or 1841. The narrowest ring is often incomplete.

The abrupt decline in radial increment, at slightly different times in different parts of the area, and the rather rapid recovery, suggest that the disturbance was not caused by competition or by climate. The temporary decline in growth resembles that caused by insect defoliation, and a spruce budworm infestation is the most plausible explanation.

METHOD OF STUDY

Field Work

Method of Sampling.—The forest was sampled by the continuous-tally strip method. This method was favoured over the line-plot method in order to record any differences in budworm damage that might occur in transition zones between main types. Each cruise strip or line was one-quarter chain wide, and of varying length, generally 40 chains. In all, almost 80 miles of tally were taken, broken down by specific localities as follows: Mississagi River 16·5 miles, Ranger Lake 23·5, Sheppard Creek 5·2, Chippewa River 7·3, Montreal River 10·4, Michipicoten River 5·7, and Manitowik Lake 9·5 miles. This total sample consisted of about 1,200 separate tallies or sample plots.

Since the basis of the sampling was the forest cover type, separate records were taken whenever a change in tree cover type occurred, when a species disappeared or a new species appeared, or when the degree of mortality of spruce and fir changed. This precaution ensured that no variation in cover type was overlooked. Each sample plot was usually at least 4 chains in length, and none was less than 2 chains. Breaking tally and separating out a cover type of small extent, which was often abruptly different from those on either side, made the sample plots on either side more homogeneous and discrete.

The strips were not run at fixed intervals, but were located to give representative coverage of the area and to sample as many different forest conditions as possible, with varying percentages of spruce and fir. Roads, railways, rivers, or lakes were used for base lines. The sample strips usually intersected the main topographic features.

Type of Records.—All trees, living and dead, were tallied by diameter classes from the 1-inch class up. In each type the crown classes* of each species

* Dominant (D)................................ Trees with crowns extending above the general level of the forest canopy and receiving full light from above and partly from the sides.

Co-dominant (CD)............................ Trees with crowns forming the general level of the forest canopy and receiving full light from above but comparatively little from the sides.

Intermediate (I)................................ Trees with crowns below, but still extending into, the general level of the forest canopy, receiving a little direct light from above but none from the sides.

Understory (U)................................ Trees with crowns entirely below the general forest canopy and receiving no direct light.

were recorded, along with an estimated height of dominant and co-dominant trees. On each strip the total ages were recorded for several balsam-fir trees. General notes were taken on topography. The topographic sites recognized, with their symbols* were:

Symbol		
V		Ridge Top
W		Upper Slope
X		Lower Slope
Y	Y_1	Dry Flat; sandy—most pine stands.
	Y_2	Ordinary Flat; good drainage, satisfactory soil
Z	Z_1	Lower Flat; deep moss, moist—good development of black spruce, larch, or cedar.
	Z_2	Wet Flat; swamp—stunted black spruce, larch, or cedar.

Compilation of data

The field tally, by number of stems, was the basis for computing basal area and total volume† for each sample plot. The samples were of varying size depending on the extent of each individual cover type. Therefore, to make comparisons among the various types, it was necessary to bring the data for each sample to a per-acre basis. In this process the portions of the strips devoid of trees (roads, rivers, flooded areas, etc.) were deducted from the size of the sample, to retain, on a per-acre basis, the actual density of trees as they occurred on forested areas.

In the compilation of tallies per acre, trees in the 1-, 2- and 3-inch diameter classes were listed separately, whereas higher diameter classes were combined into the following groups: 4-6, 7-9, 10-12, 13-18, 19 and over. The species were grouped into four categories: the chief budworm hosts (fir and spruces), other softwoods, intolerant hardwoods, and tolerant hardwoods (see Appendix B). This latter grouping formed the basis of the cover-type classification. In addition, the following data were derived for each sample plot:

(1) species distribution by percentage of the entire stand;

(2) diameter distribution by percentage within each species;

(3) percentage mortality within each diameter group of each species;

(4) total percentage mortality of each species.

All descriptive data for each sample plot were recorded on an index card. These data included an abbreviation for cover type; a list of the main tree species in declining order of importance, together with their relative heights or positions in the stand; the symbol of topographic site; total basal area of the

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* These symbols, except for a slight modification, were originally used by Mr. S. T. B. Losee of the Abitibi Power and Paper Company.

† Diameter-height curves for all species were constructed and balanced using Dwight's refinement method (10). With spruces and fir, this was done for each locality sampled. Local form-class volume tables based on Dominion Forest Service standard form-class volume tables (9) were prepared for each species, giving total volume in cubic feet.

TABLE 3

Classification of Tree Cover Type, with Symbols

I Broadest Classification	II	III	IV	V Most Specific Classi-fication	Definition	
Softwood (S)	76-100%[1] softwood (S)	88-100% softwood (S_1)[2]	S_1 FS[3]	S_1 Fb	50% or over of softwood content is Fb	50% or over of softwood content is fir-spruce
				S_1 Sw	" " " " " Sw	
				S_1 Sb	" " " " " Sb	
				S_1 FSm	Each of Fb, Sw, Sb is less than 50% of softwood content	
			S_1 P	S_1 Pw	50% or over of softwood content is Pw	50% or over of softwood content is pine
				S_1 Pr	" " " " " Pr	
				S_1 Pj	" " " " " Pj	
				S_1 Pm	Each of Pw, Pr, Pj is less than 50% of softwood content	
			S_1 C	S_1 C	50% or over of softwood content is Ce	
			S_1 L	S_1 L	50% or over of softwood content is Le	
			S_1 M	S_1 M	No single softwood species or group comprising 50% or more of softwood	
		76-87% softwood (S_2)	Same breakdown as above (S_1 replaced by S_2)			
Mixedwood (M)	51-75% softwood (SH)	Mixedwood-softwood (SH)	SHI[4]	—	50% or over of hardwood content is intolerant species	
			SHT		" " " " " " tolerant "	
	26-50% softwood (HS)	Mixedwood-hardwood (HS)	HSI	—	" " " " " " intolerant "	
			HST		" " " " " " tolerant "	
Hardwood (H)	0-25% softwood (H)	13-25% softwood (H_1)[2]	H_1 I	—	50% or over of hardwood content is intolerant species	
			H_1 T		" " " " " " tolerant "	
		0-12% softwood (H_2)	H_2 I	—	" " " " " " intolerant "	
			H_2 T		" " " " " " tolerant "	

[1] All percentages are based on basal area.
[2] When desirable, divisions into S_1 and S_2, H_1 and H_2 are dropped, and the species symbols of columns IV or V affixed to only "S" or "H".
[3] The first "S" always represents "Softwood", and the second "S" represents "Spruce".
[4] Symbols of softwood species in columns IV or V are used as subscripts to indicate the main softwood species (50%+) in mixedwood stands, e.g. SHI_{FS}. When only "SH" is used, both "SHI" and "SHT" types are included.

stand; the percentage of stand basal area, the actual basal area in square feet per acre, and the percentage mortality based on basal area, for each of balsam fir, white spruce, and black spruce.

The reason for using basal area as the basis for cover-type classification and as an expression of stand density, is as follows. In the present problem, the important aspect of stand density is the amount of foliage available to the budworm. Using the surface area of crowns as a measure of the amount of foliage, and considering fir crowns as cones and spruce crowns as frustums with cones on top, it was found that the crown surface area of all spruce and fir trees in a stand is more closely correlated with stem basal area than with total volume.

The classification of cover type is shown in Table 3. The degree of type breakdown increases from left to right, but in the analysis the breakdown is not carried beyond the fourth column. The classification of the fir-spruce and pine types in the fifth column represents a further refinement which is often desirable. This has been retained in the examples of stand tables given in Appendix B.

EXAMINATION OF BUDWORM-HAZARD CONCEPTS

Several investigators have defined forest conditions which generally lead to serious damage by the spruce budworm. One of the more recent concepts is that put forth by Westveld (36). He devised a formula for the calculation of a broad rating of hazard to damage in the event of a spruce-budworm outbreak. Westveld thought that size (which he considered synonymous with maturity) and quantity of balsam fir are the important factors governing budworm outbreaks and resultant damage, and consequently the formula takes only these two factors into account. Cover type is not considered. The vulnerability rating of any stand is expressed as the product of the balsam-fir volume in cords per acre (gross merch. vol. for trees 6 inches and over) and the basal area (in square inches) of the average fir tree at breast height.

The correspondence of vulnerability rating to hazard class is as follows:

Vulnerability Rating	*Hazard Class*
0 — 19	None
20 — 99	Low
100 — 249	Medium
250, or more	High

To test the formula, several sample plots, representing a variety of cover types and all sample strips, were selected from each locality. The suggestions regarding the proper use of the formula to calculate damage hazard as explained by McLintock (23) were followed as closely as possible; that is, all plots were one-tenth acre or more in size, and representative of the average mortality over an area of at least 50 acres. Although the latter condition was difficult to determine (no cover-type maps being available) and not always realized, the picture presented by the comparatively large number of separate sample plots for each area was considered representative.

Because of the diameter-class grouping used in the compilations, the ratings were calculated on the balsam-fir trees 7 inches D.B.H. and over. However,

the ratings obtained by this method differ little, on the average, from those obtained by using fir 6 inches and over. When only trees 7 inches and over are employed, the basal area of the average-sized tree will usually be larger, but this will be offset by a decrease in volume.

The vulnerability ratings for individual sample plots in the Mississagi area are shown in Fig. 6. The graph is sectioned to segregate plots into broad categories of damage, which are shown along the Y-axis. The vulnerability ratings

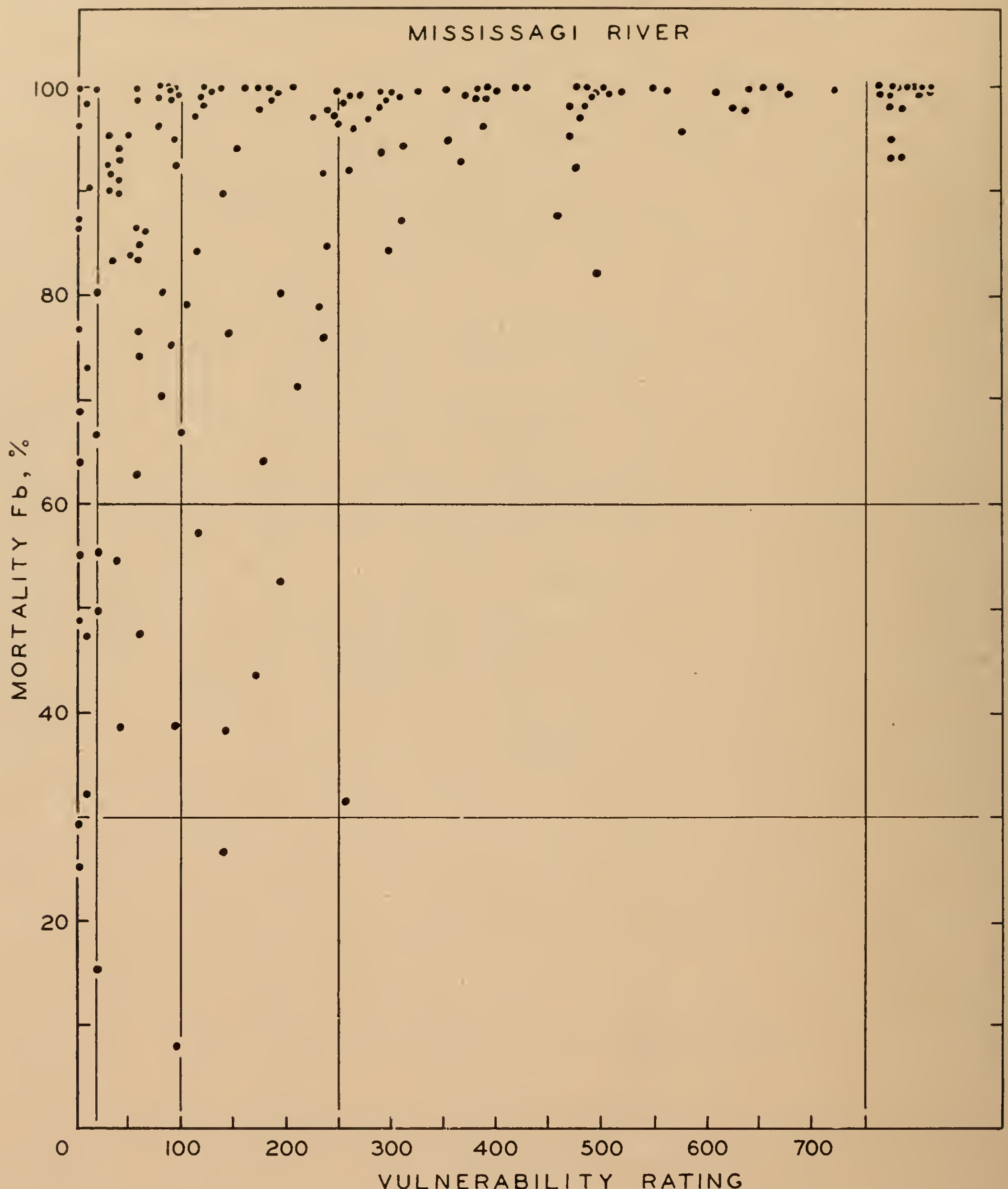

Fig. 6.—Comparison of actual mortality of fir with the theoretical vulnerability rating following Westveld's formula, in plots from the Mississagi River area (using fir trees 7 inches and over; see Table 4).

are shown on the X-axis; ratings over 750 are grouped to shorten the graph, and plotted accurately only for mortality. Table 4 summarizes the number of sample units falling in each grouping. For convenience in the tables, the hazard class "none" was combined with the "low" class.

TABLE 4

Distribution of Sample Plots, Mississagi Area, by Classes of Actual Mortality of Balsam Fir, compared with Theoretical Hazard Classes following Westveld's Formula

(using fir trees 7 inches and over)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (60-100%)	47	30	69	146	88
Medium (30-59%)	10	4	1	15	9
Low (0-29%)	4	1	—	5	3
Total	61	35	70	166	
Per Cent of whole	37	21	42		

The area as a whole would not be rated as presenting a high hazard, since only 42 per cent of the plots yielded high vulnerability ratings, and almost as many plots yielded low ratings. However, the actual average mortality of fir over the whole area was 90 per cent by basal area, or about 93 per cent by volume. Only 47 per cent of the plots with high mortality would have been classified as highly vulnerable, and only 27 per cent of the plots with medium mortality would have been classified as moderately vulnerable. Thus it appears that for the Mississagi area, the formula gives a much lower vulnerability rating than is required to portray the actual results of the infestation.

The effectiveness of the formula in portraying actual fir mortality would obviously depend to a considerable extent on the limits accepted for classes of fir mortality. Although the limits used in Table 4 appeared quite reasonable, it seemed advisable to test the formula, using other limits of actual fir mortality. Consequently, the Mississagi plots were retabulated, using 0-25 per cent fir mortality as low, 26-74 per cent as medium and 75 per cent and over as high. This new grouping failed to produce any major change in the effectiveness of the formula (Table 5).

TABLE 5

Distribution of Sample Plots, Mississagi Area, using New Limits for Classes of Actual Mortality of Balsam Fir and comparing these with Theoretical Hazard Classes following Westveld's Formula

(using fir trees 7 inches and over)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (75-100%)	39	28	69	136	82
Medium (26-74%)	20	7	1	28	17
Low (0-25%)	2	—	—	2	1
Total	61	35	70	166	
Per Cent of whole	37	21	42		

Since the presence of balsam-fir trees under 7 inches in diameter must add to the hazard, the vulnerability rating was also computed for this portion* of the stand to determine whether the combined or total rating for the stand would more closely approximate the actual percentage mortality. These new ratings are shown in Table 6.

TABLE 6

Distribution of Sample Plots, Mississagi Area, by Classes of Actual Mortality of Balsam Fir, compared with Theoretical Hazard Classes following Westveld's Formula

(using all diameter classes of fir)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (60-100%)	39	33	74	146	88
Medium (30-59%)	9	5	1	15	9
Low (0-29%)	3	2	—	5	3
Total	51	40	75	166	
Per Cent of whole	31	24	45		

For the Mississagi area as a whole, 88 per cent of all the plots had a fir mortality of at least 60 per cent. Tables 4 and 6 show that only 42 per cent and 45 per cent, respectively, of the plots are rated as possessing a high vulnerability. Similarly, 9 per cent of all the plots suffered medium mortality, while Tables 4 and 6 rate 21 per cent and 24 per cent, respectively, of the stands as presenting medium hazard. Of particular interest is the fact that only 3 per cent of the stands had less than 30 per cent mortality, whereas both tables rate over 30 per cent of the stands as having a low hazard. Adding the hazard rating for fir trees 1 to 6 inches in diameter did not materially improve the ratings in the Mississagi area. This suggests that, according to the formula, balsam-fir trees 6 inches and less in any stand do not materially increase vulnerability.

TABLE 7

Distribution of Sample Plots, Michipicoten R.-Manitowik L. Area, by Classes of Actual Mortality of Balsam Fir, compared with Theoretical Hazard Classes following Westveld's Formula

(using fir trees 7 inches and over)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (60-100%)	23	28	54	105	74
Medium (30-59%)	6	12	3	21	15
Low (0-29%)	14	2	—	16	11
Total	43	42	57	142	
Per Cent of whole	30	30	40		

* A total rating for stands was obtained by adding the rating for fir trees 6 inches and under to that computed for fir trees 7 inches and over. This procedure was necessary to increase the rating for the stand as a whole. Computing a total stand rating by including firs of all diameter classes in a single calculation would almost always lower the stand rating instead of increasing it. This would result since large numbers of small balsam-fir trees would lower considerably the basal area of the average-sized tree, and at the same time would not contribute substantially to the stand volume.

For another area of high fir mortality, namely the Michipicoten River-Manitowik Lake drainage, Fig. 7 shows the vulnerability ratings for plots in comparison with the actual fir mortality on the same plots. Table 7 summarizes the distribution of plots in the various categories. The formula did not rate the area, as a whole, as highly vulnerable since only 40 per cent of all plots were rated as having high vulnerability, and 30 per cent as having low vulnerability. Contrasted with this theoretical rating was an average fir mortality,

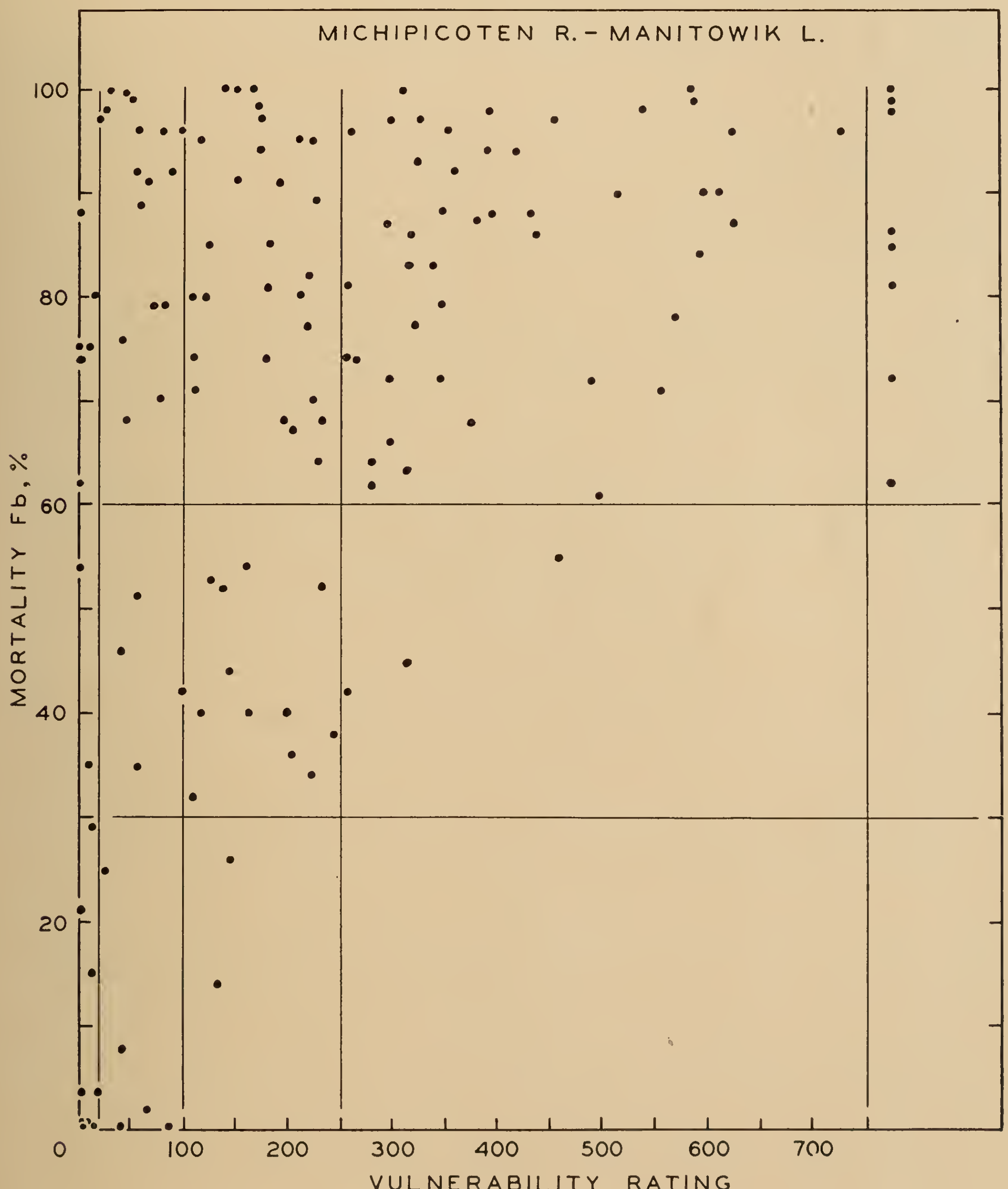

Fig. 7.—Comparison of actual mortality of fir with the theoretical vulnerability rating following Westveld's formula, in plots from the Michipicoten R.-Manitowik L. area (using fir trees 7 inches and over; see Table 7).

by basal area, of 75 per cent for the area. As in the Mississagi area, the addition of balsam firs 1 to 6 inches in diameter did not improve the ratings to any extent.

Vulnerability ratings were also calculated for two localities of less persistent attack, namely, the Sheppard Creek and Chippewa River valleys. Fig. 8 shows the plotted ratings for the Sheppard Creek area, and Tables 8 and 9 the distribution of plots falling in each category for each locality.

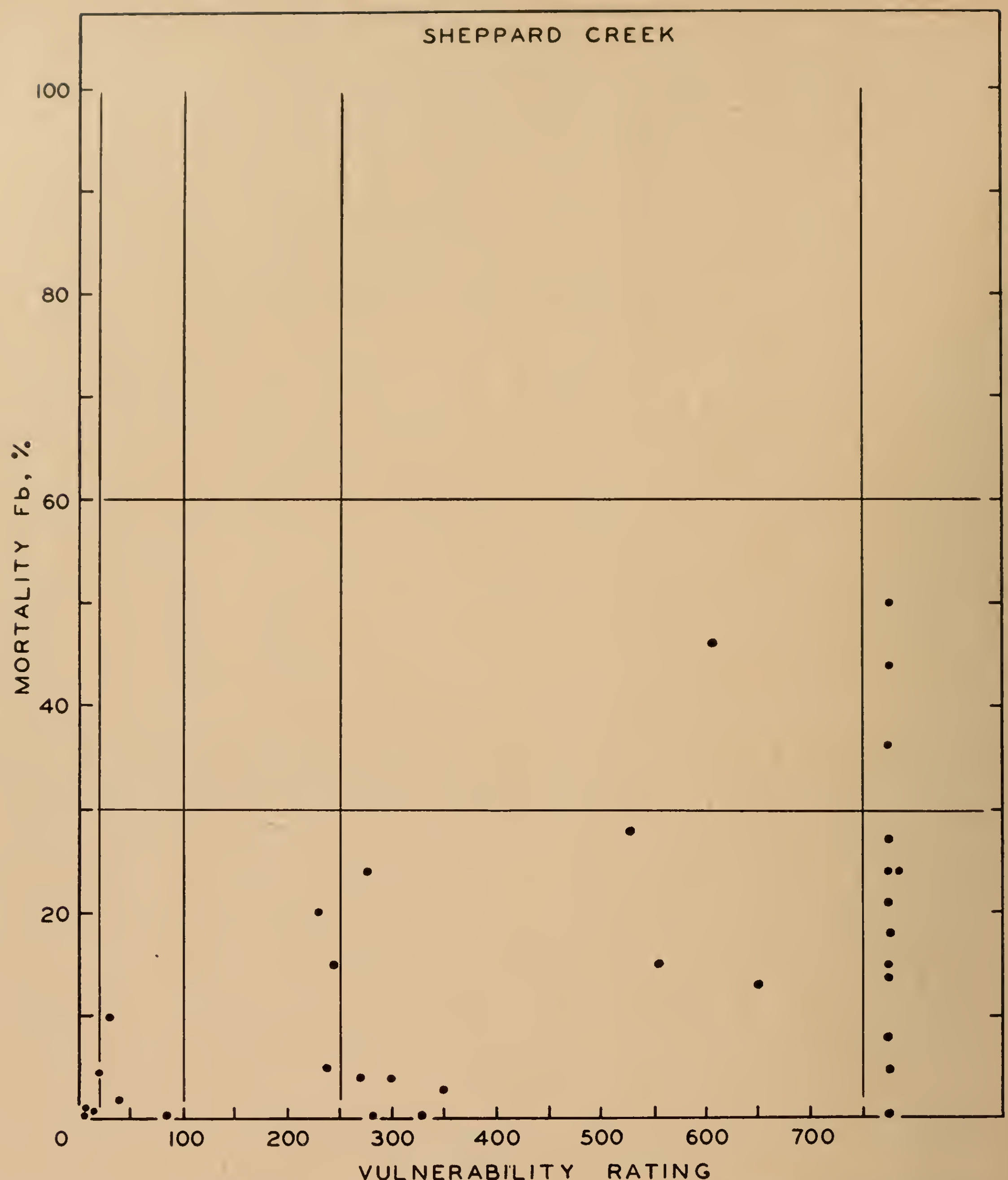

Fig. 8.—Comparison of actual mortality of fir with the theoretical vulnerability rating following Westveld's formula, in plots from the Sheppard Creek area (using fir trees 7 inches and over; see Table 8).

TABLE 8

Distribution of Sample Plots, Sheppard Creek Area, by Classes of Actual Mortality of Balsam Fir, compared with Theoretical Hazard Classes following Westveld's Formula

(using fir trees 7 inches and over)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (60-100%)	—	—	—	—	—
Medium (30-59%)	—	—	4	4	12
Low (0-29%)	7	3	19	29	88
Total	7	3	23	33	
Per Cent of whole	21	9	70		

TABLE 9

Distribution of Sample Plots, Chippewa River Area, by Classes of Actual Mortality of Balsam Fir, compared with Theoretical Hazard Classes following Westveld's Formula

(using fir trees 7 inches and over)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (60-100%)	—	—	1	1	3
Medium (30-59%)	—	1	9	10	27
Low (0-29%)	3	5	18	26	70
Total	3	6	28	37	
Per Cent of whole	8	16	76		

Since very little mortality resulted in the Sheppard Creek and Chippewa River areas in spite of high concentrations of fir (Figs. 29, 30, 31), the vulnerability ratings were quite unrelated to the actual developments in these areas.

TABLE 10

Distribution of Sample Plots, Montreal River Area, by Classes of Actual Mortality of Balsam Fir, compared with Theoretical Hazard Classes following Westveld's Formula

(using fir trees 7 inches and over)

Classes of Actual Mortality Fb by Vol.	Hazard Classes			Total	Per cent of Whole
	Low	Medium	High		
High (60-100%)	5	3	31	39	58
Medium (30-59%)	1	6	6	13	20
Low (0-29%)	8	3	4	15	22
Total	14	12	41	67	
Per Cent of whole	21	18	61		

Fig. 9 and Table 10 portray the results of ratings calculated for Montreal River plots, and as might be expected from the indicated correlation between balsam fir content and fir mortality (Fig. 2), the calculated vulnerability ratings were much more in line with actual fir mortality.

Although the vulnerability rating was in close accord with actual mortality in the rather restricted Montreal River drainage, Westveld's vulnerability-rating formula when applied to the Algoma forest as a whole failed to identify high mortality areas. Also, in areas of less persistent although intense attack, the vulnerability ratings grossly over-estimated the actual damage. In only the one locality, Montreal River, where the quantities of fir in general seemed to be positively correlated with fir mortality, did the formula come close to expressing the actual degree of damage.

Because the budworm also feeds extensively on white spruce, it was felt that by adding the white-spruce content of each stand to the balsam-fir content, and assuming that both species contribute equally to hazard, the formula

might better express the degree of fir mortality in areas of heavy damage. Although this procedure improved the accord somewhat in high-mortality plots by increasing the ratings, on the other hand it accentuated the discrepancy between calculated vulnerability rating and actual mortality of balsam fir in areas of low mortality, such as Sheppard Creek and Chippewa River.

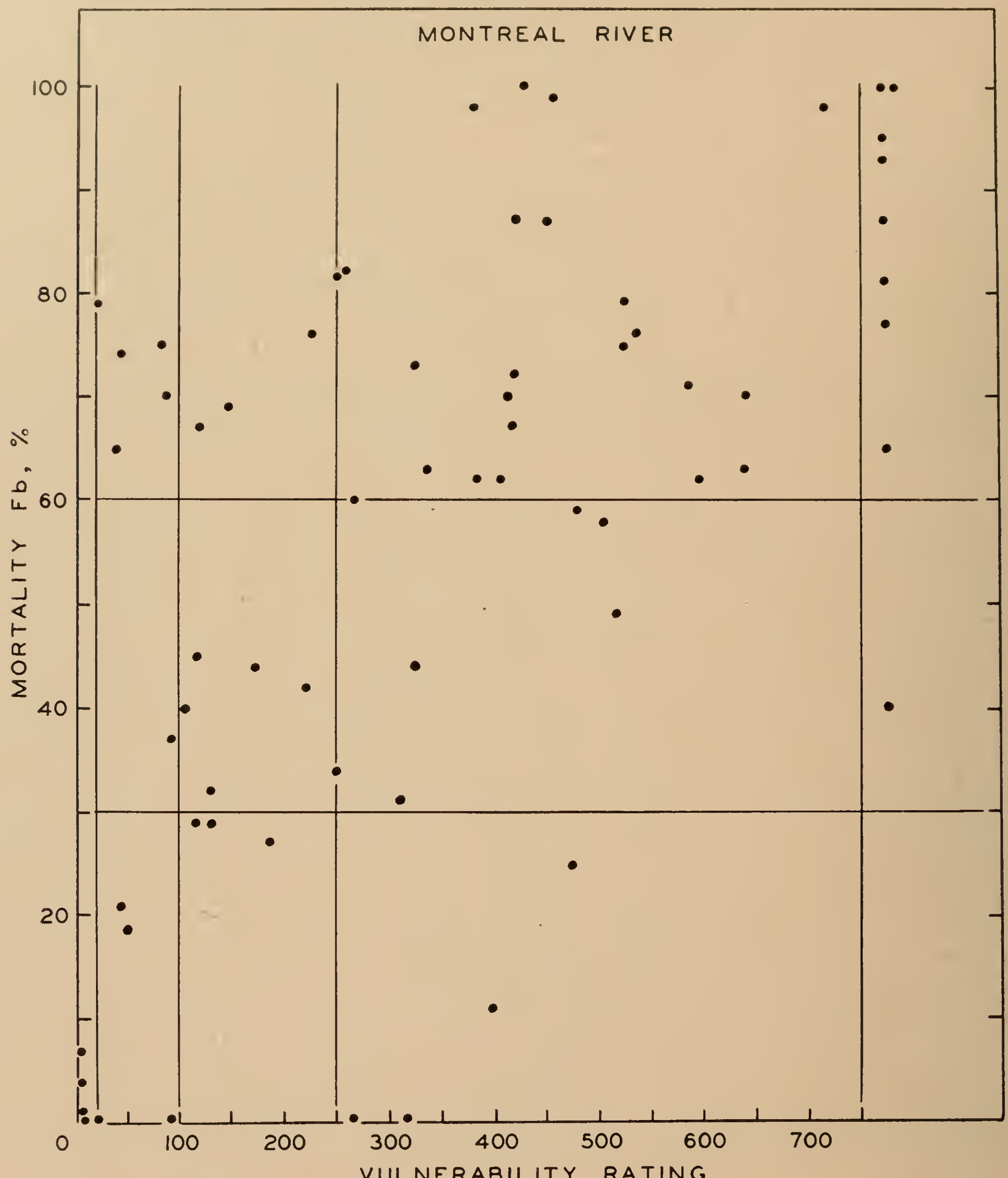

Fig. 9.—Comparison of actual mortality of fir with the theoretical vulnerability rating following Westveld's formula, in plots from the Montreal River area (using fir trees 7 inches and over; see Table 10).

To determine the relative susceptibility of the forests of New Brunswick to budworm attack, Balch (3) set up three classes of susceptibility, based on the volume of balsam fir and spruce per acre, the percentage of balsam fir in the stand, and its age.

1. *Highly Susceptible:* Areas in which mature fir-spruce stands (60 years or older) predominate and average 8 or more cords per acre, over half of which is balsam fir.

2. *Moderately Susceptible:* Areas in which the forest cannot be classified in Class 1, but the stand of fir-spruce averages over 4 cords, is over 40 years old and contains over 25 per cent balsam fir.

3. *Slightly Susceptible or Unsusceptible*: All other areas, subdivided as follows:

    A. Temporarily unsusceptible owing to the great preponderance of young stands;

    B. Permanently unsusceptible owing to the preponderance of cleared land, forest types other than fir-spruce, or recent burns.

The classes are intended to apply to large areas of at least several square miles or as much as 100 square miles, and the quoted volume figures refer to the average commercial quantities per acre over such area.

It seemed advisable to apply these susceptibility classes to the data available in the present study, to determine if they express degrees of actual damage in Algoma. In the various localities investigated in Algoma, the age of fir was generally over 60 years. Since the volume figures compiled in the present investigation represent gross total volume for all trees, living and dead, from the 1-inch class and over, several deductions were necessary to adjust the Algoma figures for comparison with the susceptibility classes. Therefore the following successive deductions were made, each of which is considered conservative:

(1) 5 per cent (an estimate) to reduce to an average content per acre in each locality, including all cover types (the indicated average quantities of fir and white spruce within each locality are possibly a little high since there was some selection of areas where fir was better represented. Also, tallies were broken in bare areas where there was no forest cover);

(2) 15 per cent, to remove the trees 1 to 4 inches in diameter (based on an examination of sample tallies);

(3) 10 per cent for fir, and 5 per cent for white spruce, to allow for normal mortality (an estimated allowance);

(4) 12 per cent, to convert total cubic volume to merchantable cubic volume (based on comparison of total and merchantable volume curves at average diameter of 8 inches);

(5) 20 per cent for fir, and 5 per cent for white spruce, to allow for cull, that is, defective trees (an estimate).

Table 11 summarizes the average balsam fir and white-spruce content and percentage mortality for each sample area in Algoma. The figures of mortality are based on the total basal area actually tallied in all cover types in each locality. The mortality figures for areas of severe damage would be slightly higher on a volume basis, since the highest mortality rate occurred among the larger trees (Table 2), and these are given greater weight on a volume basis than by basal area. Furthermore, if percentage mortality were calculated exclusively for the merchantable volume, the figures would be substantially higher than those shown in the 7th, 13th and final columns, since the mortality rate was higher in mature than in sapling trees. However, such calculations would necessitate re-working all the basic data, and this effort would be out of all proportion to the value of the results obtained.

Averaging all sample plots in the Mississagi area, the gross total volume was approximately 675 cubic feet of balsam fir per acre, and 235 cubic feet of white spruce. When the necessary deductions were made, these quantities

TABLE 11

Summary of Average Fir and White Spruce Quantities per Acre for Each Sample Area in Algoma, and the Average Percentage Mortality of each Species

Locality	Balsam Fir						White Spruce						Fb + Sw		
	B.A. per Acre	% of Forest by B.A.	Gross Total Vol. (cu.ft.)	Merch.[1] Vol. (cu.ft.)	Merch. Vol. (cds.)	% Mort. Fb by B.A.	B.A. per Acre	% of Forest by B.A.	Gross Total Vol. (cu.ft.)	Merch.[1] Vol. (cu.ft.)	Merch. Vol. (cds.)	% Mort. Sw by B.A.	Merch. Vol. (cds.)	% of Forest by B.A.	% Mort.[2] by B.A.
Mississagi River	37	22	675	346	4·1	89	11	6	235	150	1·8	59	5·9	28	82
Ranger Lake	42	34	785	402	4·7	35	8	6	165	105	1·2	19	5·9	40	32
Sheppard Creek	45	37	850	435	5·1	19	16	13	350	224	2·6	14	7·7	50	18
Chippewa River	50	41	955	489	5·8	26	9	7	195	124	1·5	26	7·3	48	26
Montreal River	37	19	675	346	4·1	69	15	8	325	209	2·4	42	6·5	27	61
Michipicoten River	50	40	895	456	5·4	79	9	8	195	124	1·5	26	6·9	48	70
Manitowik Lake	29	23	510	261	3·1	70	13	10	280	180	2·1	33	5·2	33	59

[1] Calculated by successive deductions; see text.
[2] Mortality of balsam fir and spruce combined.

were reduced to 346 and 150 cubic feet, or 4·1 and 1·8 cords, respectively. Thus, for the Mississagi area, the average merchantable content of balsam fir and white spruce did not exceed 5·9 cords per acre, and the average mortality based on all fir and white spruce trees tallied was 82 per cent by basal area. Nevertheless, the Mississagi area would not be rated high in susceptibility according to Balch's concept.

With the possible exception of the Sheppard Creek area, no area fully qualified as being highly susceptible. Therefore Balch's concept of susceptibility did not adequately portray forest conditions conducive to varying degrees of budworm damage in the Algoma area of Ontario.

The actual quantities of fir do not necessarily portray forest conditions, since the relative proportions of fir may vary considerably with the area. For instance, in both the Mississagi and Montreal River areas the content of balsam fir was only 4·1 cords per acre, but it was also a minor constituent of the forest because of the preponderance of other species. On the other hand, in the Sheppard Creek, Chippewa River, and Michipicoten River areas, balsam fir was even more important than actual quantities indicate since its relative content was also quite high (Table 11).

EVALUATION OF INDIVIDUAL VARIABLES UNDER STUDY

Of the variables recorded in the investigation, cover type, or the association and relative abundance of the tree species is the chief variable under study. However, to assess the effect of cover type, per se, on the degree of mortality of balsam fir, it was first of all necessary to determine the effect on fir mortality of each of several individual variables, viz., the total age and relative height of fir, the percentage of fir in the stand, the actual quantities of fir and of white spruce, the topographic site, and the density of the whole stand, so that any of these factors that were important could be controlled when analysing for the effect of cover type. Individual variables which were not important were dropped in further analysis, a step which eliminated considerable breakdown and thus reduced fragmentation of the data.

In all tabular analyses, the average percentage mortality of fir and white spruce for two or more plots was based on the total basal area of these species tallied on the plots.

Rejection of Unimportant Variables

Total Age of Balsam Fir

The age classes represented the maximum total age of fir in each stand, and were necessarily quite broad. In a quantitative analysis of data from two areas of high average mortality, the average percentage mortality of fir was computed for each age class (Table 12). Some measure of control over other variables was exercised by restricting the study to specific cover types in which there was not a noticeable correlation between fir mortality and quantity of fir. The lack of consistent trends and the small differences in fir mortality among age classes, indicated that fir mortality was not affected to any extent by the total age of fir. Therefore age of fir was not retained as a variable in further analysis. This conclusion pertained to stands as a whole, and does not mean that mortality may not be related to the age of individual trees. Also, in the case of fir in Algoma, where long periods of suppressed growth are usual in early life, total age may not be a satisfactory expression of age since recent work (26) indicates that age since initial release is a much more meaningful factor in the ecology of balsam fir.

TABLE 12

Percentage Mortality of Balsam Fir in Plots Segregated by Cover Type and Total Age of Fir

Mississagi River

Cover Type: SHIfs	Age Classes of Fb		
	Up to 75	76–100	101+
Average % mortality Fb	84	78	94
Number of sample plots	16	11	19
Acres tallied	1·600	1·012	1·550
Average basal area Fb per acre	33	52	52

Michipicoten River - Manitowik Lake

Cover Type: SFS	Age Classes of Fb		
	Up to 75	76–100	101+
Average % mortality Fb	85	85	84
Number of sample plots	12	17	14
Acres tallied	1·700	1·750	1·300
Average basal area Fb per acre	43	58	56

Cover Type: SHIfs	Age Classes of Fb		
	Up to 75	76–100	101+
Average % mortality Fb	78	80	81
Number of sample plots	6	20	24
Acres tallied	0·475	2·875	3·925
Average basal area Fb per acre	58	44	48

Topographic Site

In a qualitative analysis of the influence of topographic site on fir mortality, plots from the Michipicoten R.–Manitowik L., Mississagi R., and Montreal R. areas were grouped by topographic site, broad cover type, and by above-average or below-average mortality of fir compared with the mean for the group of plots of similar detailed cover type and percentage of fir. To increase the number of samples for analysis, sample plots from dry flats and ordinary flats were pooled, as were those from moist flats and swamps. This analysis did not yield consistent results (Table 13). A serious difficulty with this method of analysis is that it does not indicate the absolute degree of mortality, thus preventing a close comparison among the sites.

Therefore, to determine whether topographic site should be retained as an important variable in the analysis of cover type, the preliminary evidence was re-tested by tabulation of the data, with possibly important associated factors

held under control. Therefore, balsam fir and white spruce content was defined within definite limits, and the test was further restricted to specific cover types. The test was carried out with plots from Manitowik Lake, Michipicoten River, the eastern portion of the Montreal River area (Fig. 2, Strips 101 to 107), and the northeastern portion of the Ranger Lake area (Strips 46-51). These localities were selected because the over-all degree of mortality (between 70 and 80 per cent for balsam fir) and the range of variability were approximately the same,

TABLE 13

Distribution of Plots Grouped by Topographic Site, Broad Cover Type, and by Above-average or Below-average Mortality of Fir Compared with the Mean for the Group of Plots of Similar Detailed Cover Type and Percentage of Fir

Locality	Broad Cover Type	Topographic Site									
		V		W		X		Y		Z	
		+[1]	−[2]	+	−	+	−	+	−	+	−
Michipicoten R.-Manitowik L.	S	1	2	7	3	12	10	13	9	1	1
	SH	4	3	7	1	12	17	5	6	—	—
	HS	1	—	8	4	13	9	10	11	—	—
	H	—	1	1	1	2	8	2	2	—	—
	Total	6	6	23	9	39	44	30	28	1	1
Mississagi River	S	—	3	7	16	31	17	28	15	6	8
	SH	3	2	4	16	30	12	9	7	4	—
	HS	4	1	12	12	8	7	4	2	1	—
	H	1	5	9	5	2	1	2	1	—	—
	Total	8	11	32	49	71	37	43	25	11	8
Montreal River	S	1	3	5	5	10	4	14	12	5	6
	SH	5	1	5	8	15	8	10	14	1	—
	HS	3	4	5	5	7	8	7	6	—	—
	H	1	1	3	9	10	18	4	2	—	1
	Total	10	9	18	27	42	38	35	34	6	7

[1] Number of plots with *above-average* mortality of fir for groups of similar detailed cover type and percentage of fir.

[2] Number of plots with *below-average* mortality of fir for groups of similar detailed cover type and percentage of fir.

thus possibly eliminating intensity and duration of attack as a variable. Three cover types were selected, viz. SFS, SHI_{FS} and HSI_{FS}, representing known proportions of hardwood and budworm-host species. All samples from each cover type were sorted in tabular form according to the topographic site, the fir basal area per acre, and the white spruce basal area per acre. With the breakdown into three variables within each type, fifty-two tables resulted, of which Table 14 is an example. The contents of all these tables are brought together in Table 15, where the percentage mortality of balsam fir, white spruce, and fir plus white spruce is arranged for easy comparison according to the various topographic sites, when the fir and white spruce content remains constant within each specific type.

TABLE 14

A Sample Table from Study to Determine Relation of Topographic Site to Mortality of Fir and White Spruce

Cover Type: SFS Topographic Site: X
Fb Range: 21–40 square feet, basal area per acre

Basal Area of Sw per Acre	No. of Sample Plots	Total Acres Tallied	Species	Total B.A.	Dead B.A.	% Dead
0–10	2	0·300	Fb Sw	11·98 2·66	8·67 0·20	72 8
			Total	14·64	8·87	61
11–20	2	0·200	Fb Sw	6·11 2·22	5·75 0·54	94 24
			Total	8·33	6·29	76
21–30	2	0·100	Fb Sw	3·53 2·90	2·76 1·85	78 64
			Total	6·43	4·61	72
31–40	2	0·200	Fb Sw	7·97 6·73	6·93 3·15	87 47
			Total	14·70	10·08	69
41 +	—	—	—	—	—	—
Total	8	0·800	Fb Sw	29·59 14·51	24·11 5·74	81 40
			Total	44·10	29•85	68

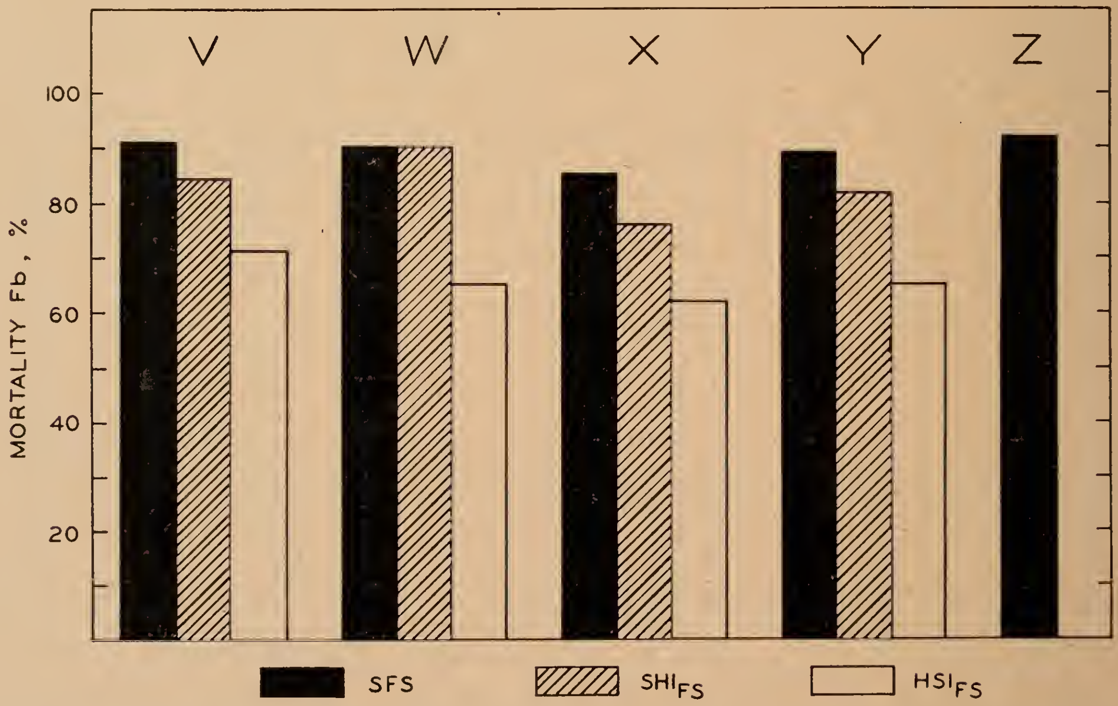

Fig. 10.—Percentage mortality of balsam fir by topographic sites for three detailed cover types from localities where over-all fir mortality was moderately high (see Table 16).

The data in Table 15 do not show consistent trends between balsam fir or white spruce mortality and topography. There is perhaps some indication that fir mortality was less on lower slopes ("X" sites), but this tends to break down where larger quantities of fir are involved.

TABLE 15

Percentage Mortality of Balsam Fir and White Spruce by Topographic Sites, Keeping Cover Type, Basal Area per Acre of Fir and of Spruce, and Over-all Degree of Damage Relatively Constant

Basal Area of White Spruce, Sq. Ft. per acre

Topog. Site	0 - 10	11 - 20	21 - 30	31 - 40	41 +	0 - 10	11 - 20	21 - 30	31 - 40	41 +	0 - 10	11 - 20	21 - 30	31 - 40	41 +	0 - 10	11 - 20	21 - 30	31 - 40	41 +	0 - 10	11 - 20	21 - 30	31 - 40	0 - 10	11 - 20	21 - 30	41 +
	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.[1]	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.	Fb Sw Tot.
Cover Type: SFS																												
V	—	—	—	—	—	—	—	—	—	—	—	—	99 48 82 (1)[2]	—	—	—	79 0 66 (1)	—	—	—	—	—	—	—	—	—	—	—
W	—	—	—	—	—	—	—	81 54 67 (1)	99 78 88 (1)	—	77 0 69 (2)	100 29 83 (1)	73 43 62 (2)	94 59 78 (1)	—	—	—	—	99 16 68 (1)	66 0 38 (1)	—	—	98 42 85 (2)	—	96 30 90 (1)	—	—	—
X	—	4 0 2 (1)	74 0 22 (1)	—	—	72 8 61 (2)	94 24 76 (2)	78 64 72 (2)	87 47 69 (2)	—	91 0 85 (2)	50 11 40 (2)	98 61 85 (2)	92 91 92 (1)	92 77 83 (2)	61 25 59 (3)	83 82 71 (2)	68 0 51 (1)	—	99 54 83 (1)	95 57 94 (5)	81 0 69 (2)	—	—	99 0 98 (2)	—	99 31 88 (1)	100 0 67 (1)
Y	32 0 27 (1)	—	—	—	44 0 3 (2)	18 0 15 (1)	—	94 30 65 (1)	93 20 54 (1)	—	80 22 75 (7)	—	—	100 55 81 (1)	82 88 86 (1)	88 3 84 (7)	94 100 95 (2)	—	98 72 90 (1)	89 84 86 (5)	68 100 70 (1)	98 72 94 (2)	94 32 80 (2)	—	98 100 98 (3)	97 24 86 (2)	—	—
Z	75 44 64 (2)	—	81 35 49 (1)	—	—	95 0 94 (2)	—	—	90 77 84 (1)	—	69 0 69 (1)	—	—	94 2 54 (1)	—	97 30 92 (2)	—	—	—	—	—	—	—	—	—	—	—	—
Cover Type: SHI$_{Fs}$																												
V	—	—	—	—	—	—	70 71 70 (1)	—	—	88 53 59 (1)	86 21 79 (3)	93 14 79 (1)	—	66 52 61 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
W	—	—	—	—	—	93 33 82 (1)	80 69 75 (1)	85 83 84 (1)	96 18 49 (1)	94 26 53 (1)	—	—	92 38 72 (1)	94 16 61 (1)	—	85 0 84 (2)	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	12 18 16 (2)	57 11 25 (1)	—	74 80 74 (3)	41 17 33 (1)	47 9 30 (1)	75 71 73 (1)	—	76 42 72 (7)	68 21 58 (3)	—	90 22 61 (1)	—	100 12 90 (2)	89 17 76 (2)	80 40 70 (1)	93 45 76 (2)	52 81 63 (1)	83 11 81 (5)	87 100 90 (1)	—	—	100 0 99 (1)	—	—	—
Y	—	64 0 38 (1)	—	99 58 72 (2)	—	81 0 66 (3)	—	—	—	—	90 4 83 (2)	92 0 73 (1)	97 27 77 (1)	—	—	89 0 80 (2)	87 35 78 (1)	—	—	—	69 71 69 (2)	58 31 54 (1)	—	74 98 81 (1)	—	—	—	—
Cover Type: HSI$_{Fs}$																												
V	—	—	—	—	—	—	—	77 70 74 (2)	—	52 100 80 (1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
W	—	—	—	96 19 44 (1)	—	59 13 52 (4)	69 64 68 (4)	60 52 56 (1)	—	—	73 43 70 (3)	—	41 22 34 (1)	—	—	42 0 38 (1)	—	—	—	—	—	—	—	—	—	—	—	—
X	66 0 39 (3)	67 0 41 (1)	—	—	94 35 40 (1)	56 36 54 (6)	43 19 36 (3)	46 33 40 (3)	—	—	83 15 77 (4)	54 15 46 (1)	—	—	—	76 17 72 (1)	89 54 81 (1)	—	—	—	—	—	—	—	—	—	—	—
Y	70 39 61 (4)	48 15 34 (4)	0 4 [illegible] (1)	70 0 21 (1)	—	62 30 58 (7)	70 44 61 (2)	23 0 12 (1)	—	—	76 31 73 (2)	84 0 69 (1)	—	—	—	61 — 61 (1)	—	—	—	—	—	—	—	—	—	—	—	—
	0 - 20					21 - 40					41 - 60					61 - 80					81 - 100				101 +			

Basal Area of Balsam Fir, Sq. Ft. per Acre

[1] Percentage mortality of balsam fir plus white spruce.
[2] Figures in brackets refer to number of sample plots.

In Table 16, for individual cover types, all classes of white spruce content are combined, and mortalities of fir, white spruce, and fir plus white spruce are compared by fir-content groups and topographic sites only. Here again there is some indication that balsam-fir mortality, in particular, was slightly less on lower slopes, compared with flats and upper slopes. This indication became more evident with further grouping of the data (see bottom of Table 16 and Fig. 10). Quantities per acre of fir and white spruce did not appear to have

TABLE 16

Percentage Mortality of Fir, White Spruce, and Fir plus White Spruce, by Topographic Sites, With and Without Control of Fir Content

Cover Type:		SFS					SHI$_{FS}$					HSI$_{FS}$				
Basal Area Fb	Topog. Site	n[1]	Acres Tallied	% Dead			n	Acres Tallied	% Dead			n	Acres Tallied	% Dead		
				Fb	Sw	Tot.			Fb	Sw	Tot.			Fb	Sw	Tot.
0–20	V	—	—	—	—	—	1	0·050	88	53	59	—	—	—	—	—
	W	—	—	—	—	—	—	—	—	—	—	1	0·200	96	19	44
	X	2	0·200	29	0	13	3	0·275	23	16	18	5	0·425	70	26	40
	Y	3	0·325	34	0	8	3	0·400	91	52	67	10	1·125	54	12	33
	Z	3	0·400	76	40	61	—	—	—	—	—	—	—	—	—	—
21–40	V	—	—	—	—	—	1	0·250	70	71	70	3	0·250	71	80	75
	W	2	0·225	94	71	82	5	0·425	91	34	61	9	1·400	65	55	62
	X	8	0·800	81	40	68	6	1·300	68	45	63	12	2·225	48	28	42
	Y	3	0·375	78	23	53	3	0·375	81	0	66	10	1·475	63	34	57
	Z	3	0·300	94	74	91	—	—	—	—	—	—	—	—	—	—
41–60	V	1	0·100	99	48	82	5	1·000	86	28	76	—	—	—	—	—
	W	6	0·500	79	41	68	2	0·400	92	32	69	4	0·650	66	32	60
	X	9	1·075	89	71	83	11	1·400	73	28	66	5	0·750	76	15	69
	Y	9	1·425	83	53	77	4	0·700	92	15	79	3	0·400	77	22	72
	Z	2	0·100	82	2	59	—	—	—	—	—	—	—	—	—	—
61–80	V	1	0·050	79	0	66	—	—	—	—	—	—	—	—	—	—
	W	2	0·225	80	6	51	2	0·175	85	0	84	1	0·075	42	0	38
	X	7	0·775	75	37	68	8	0·700	88	39	76	2	0·275	85	50	79
	Y	15	1·375	90	78	87	3	0·425	88	17	80	1	0·050	61	—	61
	Z	2	0·300	97	1	92	—	—	—	—	—	—	—	—	—	—
81–100	W	2	0·350	98	42	85	—	—	—	—	—	—	—	—	—	—
	X	7	0·700	89	15	83	6	0·400	84	63	82	—	—	—	—	—
	Y	5	0·775	92	49	84	4	0·425	68	79	69	—	—	—	—	—
101+	W	1	0·225	96	30	90	—	—	—	—	—	—	—	—	—	—
	X	4	0·300	99	15	88	—	—	—	—	—	—	—	—	—	—
	Y	5	0·450	98	36	91	—	—	—	—	—	—	—	—	—	—

		SFS Av. B.A.			SFS % Dead			SHI$_{FS}$ Av. B.A.			SHI$_{FS}$ % Dead			HSI$_{FS}$ Av. B.A.			HSI$_{FS}$ % Dead		
		Fb	Sw	Tot.	Fb	Sw	Tot.	Fb	Sw	Tot.	Fb	Sw	Tot.	Fb	Sw	Tot.	Fb	Sw	Tot.
All Fb Basal Area Groups Combined	V	60	22	82	91	37	77	46	13	59	84	41	75	30	30	59	71	80	75
	W	67	26	92	90	38	76	45	26	71	90	33	69	34	14	49	65	42	58
	X	61	18	79	85	46	74	50	12	62	76	35	68	34	14	48	62	28	52
	Y	65	19	84	89	53	81	51	13	64	82	39	74	28	10	38	65	21	54
	Z	40	8	48	92	38	83	—	—	—	—	—	—	—	—	—	—	—	—

[1] Number of Sample Plots

any connection with this trend (see bottom of Table 16). Some investigators (20) found that stands on all sites were equally subject to attack by the budworm and therefore differences in mortality would not likely come from this source.

However, evidence of inconsistent effects of topographic site on fir mortality (Table 13), and the small differences in fir mortality among topographic sites with the same cover type (Fig. 10), indicated that topographic site did not have sufficient influence on fir mortality to justify its retention as a variable in further analyses.

Review of Remaining Variables

Five variables remained to be examined, namely, basal area, percentage content and relative height of fir, basal area of white spruce, and basal area of the whole stand. The effect of these variables on fir mortality was analysed following a somewhat different procedure from that followed for age of fir and topographic site. In exploratory graphic trials to discover which of the variables might be correlated with fir mortality, the percentage mortality of balsam fir was related to each variable singly, all other variables being uncontrolled. This procedure was carried out within both detailed and general cover types of each sample area. Since all other variables, except the one under immediate consideration, were uncontrolled, the results from this type of analysis were merely suggestive and not conclusive in themselves. Figs. 11 and 12 illustrate the type of analysis.

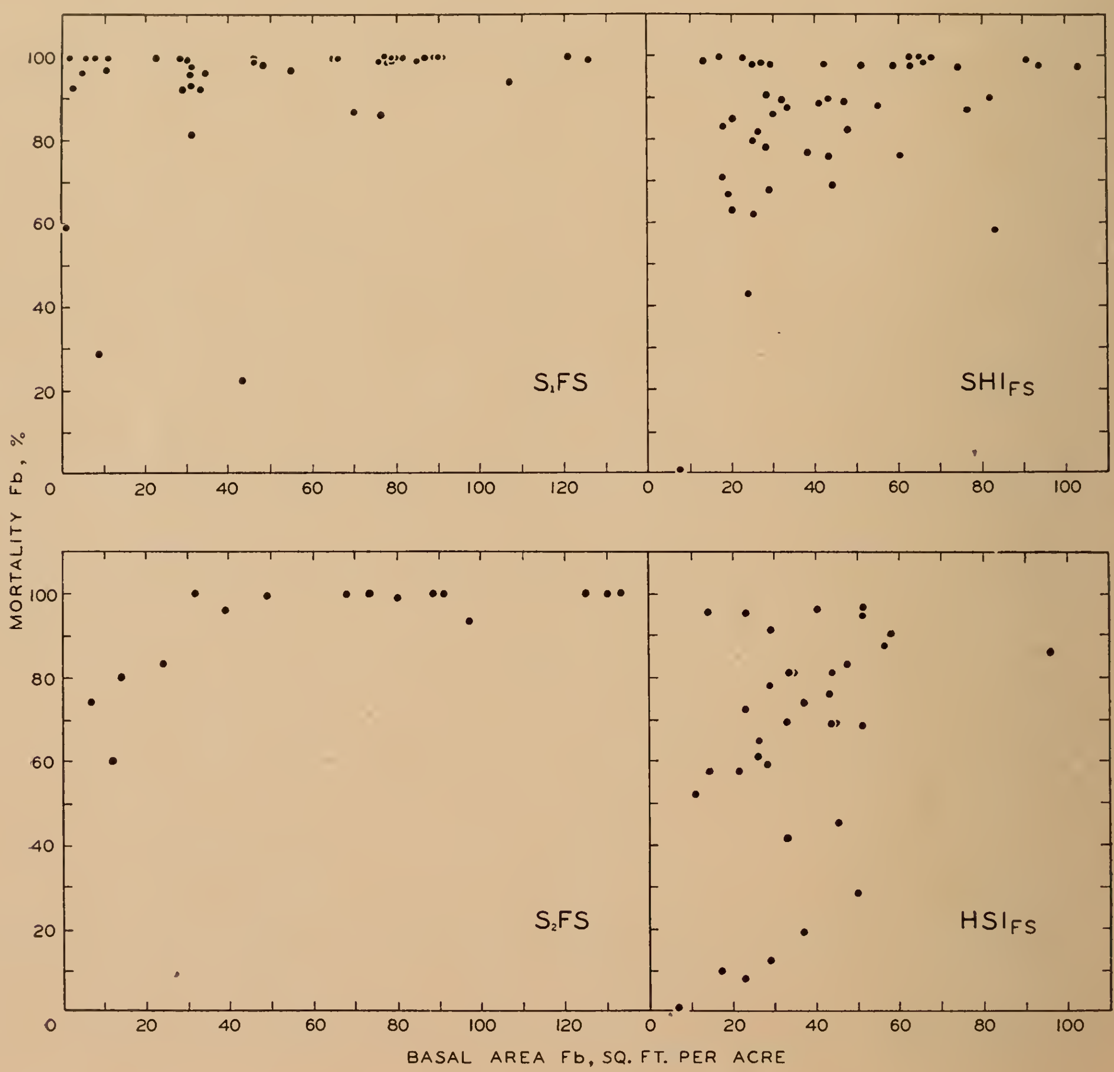

Fig. 11.—Relation of percentage mortality of fir to basal area of fir in plots where the softwood component is mainly fir and spruce (Mississagi River area). The types differ principally by successive increases in the proportions of hardwood, from S_1FS, through S_2 and SH, to HSI_{FS}.

In a more critical analysis of the effect of each of the above variables on fir mortality, all plots from the areas where the over-all degree of fir mortality was moderately high were separated into three broad cover types (S, SH and HS) and tabulated in large tables, keeping each of the above variables under control. Table 17 is a sample section from the larger arrangement shown in Fig. 13, which includes the whole basal area range of fir and white spruce.

Therefore studies could be made of the relation of fir mortality to increasing amounts of any one factor, the others being kept within definite limits.

Table 18, showing the relation of fir mortality to basal area of fir when the remaining four variables are controlled within limits, illustrates the procedure followed to assess the relation of fir mortality to each of the five variables under immediate study. In the first line of Table 18 five plots are involved. The forest composition on all of these plots was similar in that the white-spruce

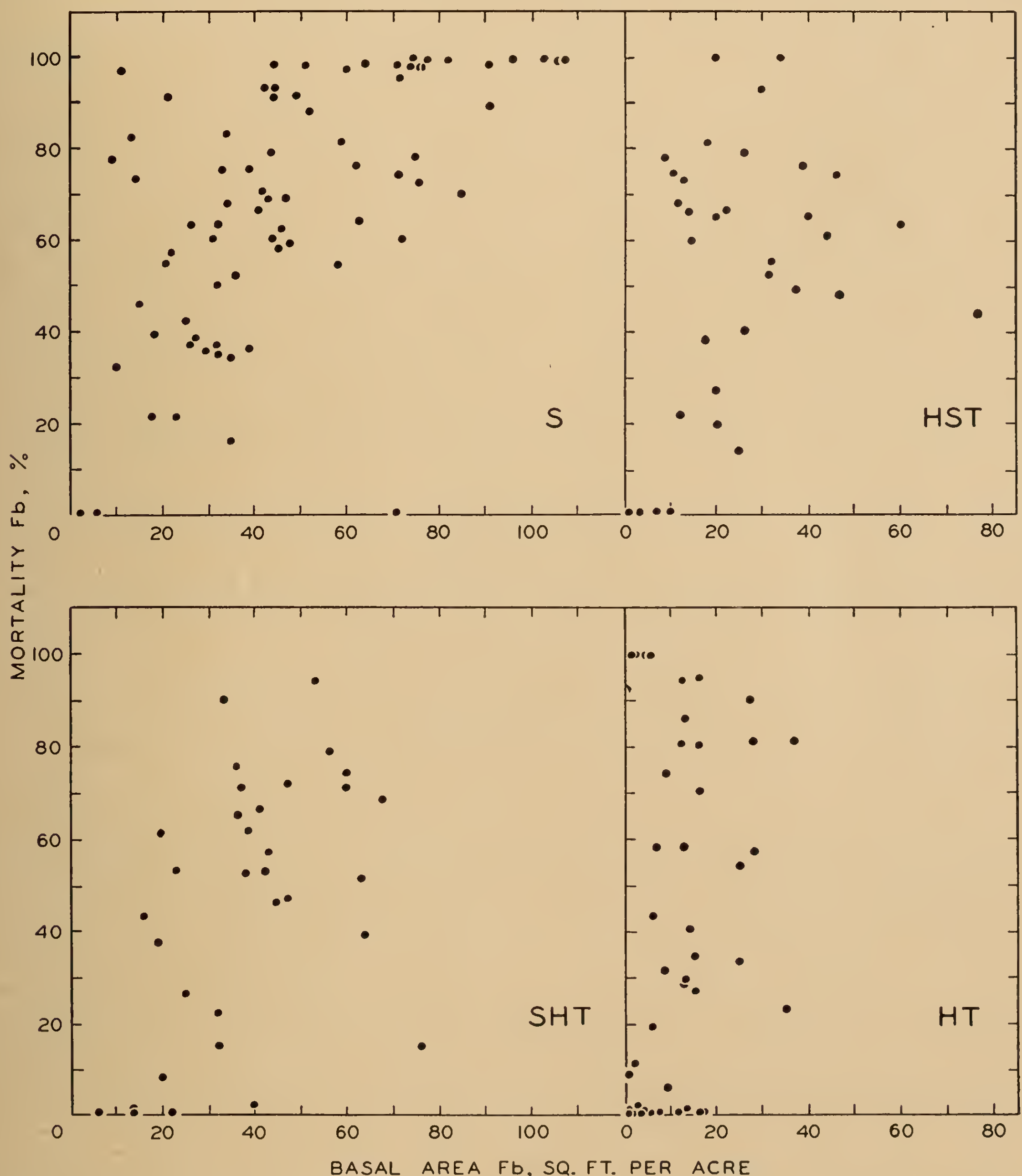

Fig. 12.—Relation of percentage mortality of fir to basal area of fir in plots classified within the S, SHT, HST and HT cover types (Montreal River area).

content was not over 10 sq. ft. per acre, the proportion of fir was between 41 and 60 per cent of the stand, the total stand density was between 51 and 100 sq. ft. per acre, and the firs were not more than intermediate in relative height. The main difference between the two groups of plots was the basal area of fir, and it is the effect of this variable on fir mortality that is portrayed in the first line of the table.

Because of the limited number of plots available for analysis when all measured variables were controlled, it was not possible to apply statistical

TABLE 17

Percentage Mortality of Fir and White Spruce, and Number of Sample Plots for Stands Containing Specified Limits of Basal Area, Percentage Content and Relative Height of Fir, Basal Area of White Spruce and Basal Area of the Whole Stand (see Fig. 13)

B.A. Sw	Total B.A. of Stand	Rel. Ht. Fb	Percentage Fb in Stands														
			0–20			21–40			41–60			61–80			81–100		
			Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n
	301+	CD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		I	62	0	2	—	—	—	—	—	—	—	—	—	—	—	—
		U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	251–300	CD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		I	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	201–250	CD	100	—	1	97	0	1	—	—	—	—	—	—	—	—	—
		I	—	—	—	66	0	2	—	—	—	—	—	—	—	—	—
		U	—	—	—	71	13	1	—	—	—	—	—	—	—	—	—
	151–200	CD	—	—	—	58	0	1	—	—	—	—	—	—	—	—	—
0–10		I	—	—	—	77	13	4	—	—	—	—	—	—	—	—	—
		U	—	—	—	26	0	1	—	—	—	—	—	—	—	—	—
	101–150	CD	—	—	—	—	—	—	99	0	1	94	100	1	—	—	—
		I	—	—	—	77	27	3	72	3	2	—	—	—	—	—	—
		U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	51–100	CD	—	—	—	—	—	—	86	0	1	91	0	1	—	—	—
		I	—	—	—	—	—	—	86	19	3	68	0	1	—	—	—
		U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	0–50	CD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		I	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

41–60 sq. ft., basal area Fb per acre

techniques to assess the role of the independent variable in each case. Hence the whole series of values presented in all tables similar to Table 18 may be examined for trends rather than for actual correlations. Each horizontal series of mortality values corresponding to increasing quantities of the independent variable was regarded as a set of observations which showed (a) increasing balsam fir mortality with increasing quantities of the independent variable (marked*), (b) decreasing mortality with increasing amounts of the independent variable (marked **) or (c) no consistent trend, or differences in mortality less than 5 per cent (not marked). The importance of each independent variable was assessed according to the percentage occurrence of each type of trend.

Although the control of all variables was a very desirable condition for analysis, it fragmented the data so that only single-plot calculations of mortality were possible in many cases. Consequently the analysis was broadened by retaining only those variables which, as will be described later, were found to be important. The rejection of unimportant variables often brought out trends which were obscured when all variables were controlled, perhaps indicating that increased numbers of observations more than made up for the accompanying submergence of variables in the analysis. Finally, each variable was related to mortality of fir in a scatter-diagram, without control of any other variables except the size of plot and the broad cover type (Fig. 18). The degree of association, in a two-fold contingency table, was then determined by the Chi-square test of independence.

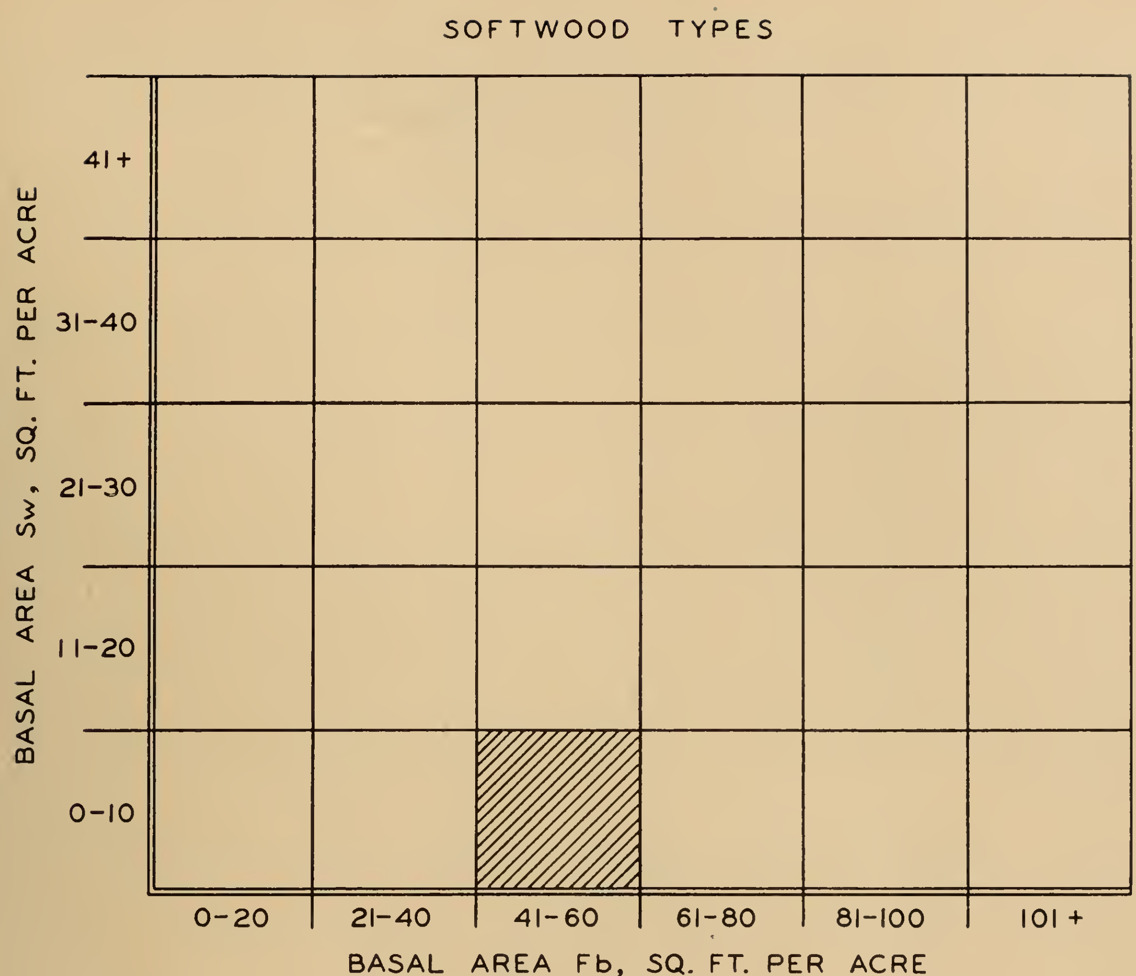

Fig. 13.—Outline of arrangement used for assessing the influence on degree of fir mortality, within any one broad cover type, of each of five variables. The main sub-divisions are based on the quantities of fir and white spruce. Each segment is further broken down on the basis of the three remaining variables. The sample segment (hatched) is shown in detail in Table 17.

Basal Area of Balsam Fir

Except in occasional detailed types, especially those of the softwood group, the preliminary graphic analysis did not reveal a close association between fir mortality and basal area of fir (Figs. 11 and 12). The results of the more adequate analysis are given below.

(1) Softwood Types (S)

The data in Table 18 show a slight tendency for fir mortality to increase with quantity of fir. The analysis was broadened by retaining control only of basal area of white spruce and relative height of fir (Table 19); there is good evidence, especially in the "average" rows where relative height of fir is ignored, that fir mortality increased with basal area of fir.

The average mortality of balsam fir and white spruce by basal area classes of balsam fir (bottom line, Table 19) is shown in Fig. 14. The decline in percentage mortality of white spruce in plots containing about 80 sq. ft. or more of balsam fir per acre was a result not of the increased balsam-fir content, but rather of the decreased white-spruce content. Since both species normally compete for the same site, an increase in the quantity of one species in fir-spruce stands must, after a certain density is reached, be at the expense of the other. Fig. 15 shows that white spruce development was best where fir was present in quantities of 61 to 80 sq. ft. per acre; it was poor where fir was best, and poor where fir was poorest. Therefore the degree of white spruce mortality was, at the most, only partially correlated with the amount of balsam fir (see body of Table 19 also).

TABLE 18

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of Balsam Fir, with Control of Basal Area of White Spruce and of the Whole Stand, and of the Relative Height and Percentage Content of Fir

Broad Cover Type: Softwood

Variables Controlled within Indicated Limits				Basal Area of Fb												Trend
				0–20		21–40		41–60		61–80		81–100		101+		
B.A. Sw	% Fb	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–10	41–60	51–100	I	—	—	81	3	86	2	—	—	—	—	—	—	*
0–10	61–80	51–100	I	—	—	—	—	68	1	96	1	—	—	—	—	*
0–10	21–40	101–150	I	—	—	91	1	77	3	—	—	—	—	—	—	**
0–10	41–60	101–150	I	—	—	—	—	72	2	71	2	—	—	—	—	
0–10	61–80	101–150	I	—	—	—	—	—	—	100	1	99	1	—	—	
0–10	41–60	101–150	CD	—	—	—	—	99	1	96	2	76	1	—	—	**
0–10	61–80	101–150	CD	—	—	—	—	94	1	—	—	70	2	97	2	
0–10	81–100	101–150	CD	—	—	—	—	—	—	—	—	100	1	98	2	
0–10	0–20	151–200	U	10	2	70	1	—	—	—	—	—	—	—	—	*
0–10	21–40	151–200	U	—	—	—	—	26	1	72	1	—	—	—	—	*
0–10	0–20	151–200	I	70	1	91	3	—	—	—	—	—	—	—	—	*
0–10	21–40	151–200	I	—	—	66	1	77	4	95	1	—	—	—	—	*
0–10	41–60	151–200	I	—	—	—	—	—	—	96	2	98	1	—	—	
0–10	21–40	201–250	I	—	—	—	—	66	2	26	1	—	—	—	—	**
0–10	0–20	251–300	I	0	1	58	3	—	—	—	—	—	—	—	—	*
11–20	41–60	151–200	CD	—	—	—	—	—	—	98	1	70	1	—	—	**
21–30	21–40	101–150	CD	—	—	100	1	98	1	—	—	—	—	—	—	
21–30	41–60	101–150	I	—	—	—	—	98	1	68	1	—	—	—	—	**
31–40	21–40	151–200	I	—	—	—	—	92	1	99	1	—	—	—	—	*
41 +	41–60	151–200	CD	—	—	—	—	—	—	98	2	—	—	100	1	

	No.	%
Increasing mortality with increasing basal area Fb (*)...................	8	40
Decreasing mortality with increasing basal area Fb (**)...............	5	25
No trend...	7	35
Total observations...	20	

TABLE 19

Percentage Mortality of Balsam Fir and of White Spruce in Plots Segregated on the Basis of Basal Area and Relative Height of Fir, and Basal Area of White Spruce

Broad Cover Type: Softwood

Basal Area Sw	Rel. Ht. Fb	Basal Area of Fb																		Average % Mort.		Total
		0–20			21–40			41–60			61–80			81–100			101+					
		Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Fb	Sw	n
0–10	CD	—	—	—	—	—	—	91	29	7	92	6	4	78	99	4	97	35	4			
	I	70	44	3	78	22	14	74	11	16	82	13	8	99	57	2	98	100	2			
	U	14	14	8	38	0	2	55	7	2	72	47	1	—	—	—	—	—	—			
	Average	35	24	11	75	21	16	77	13	25	84	18	13	89	70	6	98	48	6	81	23	77
11–20	CD	—	—	—	73	22	4	100	29	1	89	59	2	87	14	3	97	24	2			
	I	—	—	—	60	27	2	84	2	2	86	30	4	99	84	2	—	—	—			
	U	2	10	3	—	—	—	34	16	1	—	—	—	—	—	—	—	—	—			
	Average	2	10	3	69	24	6	77	11	4	87	43	6	91	38	5	97	24	2	85	28	26
21–30	CD	—	—	—	100	0	1	84	48	3	—	—	—	95	31	3	—	—	—			
	I	77	12	2	86	49	3	91	55	2	79	35	2	98	75	1	99	31	1			
	U	0	0	1	90	30	1	—	—	—	98	70	1	—	—	—	—	—	—			
	Average	65	9	3	88	41	5	87	50	5	89	52	3	96	37	4	99	31	1	92	40	21
31–40	CD	—	—	—	—	—	—	70	6	1	98	72	1	—	—	—	—	—	—			
	I	—	—	—	91	63	4	95	67	4	99	16	1	—	—	—	—	—	—			
	U	—	—	—	93	20	1	—	—	—	—	—	—	—	—	—	—	—	—			
	Average	—	—	—	92	51	5	92	66	5	98	43	2	—	—	—	—	—	—	93	57	12
41 +	CD	0	0	1	—	—	—	89	81	3	85	85	3	—	—	—	100	0	1			
	I	99	70	1	—	—	—	—	—	—	91	49	4	—	—	—	—	—	—			
	U	100	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
	Average	82	16	3	—	—	—	89	81	3	88	66	7	—	—	—	100	0	1	89	60	14
Total Average		35	16	20	78	39	32	80	52	42	87	56	31	92	40	15	98	27	10	85	44	150

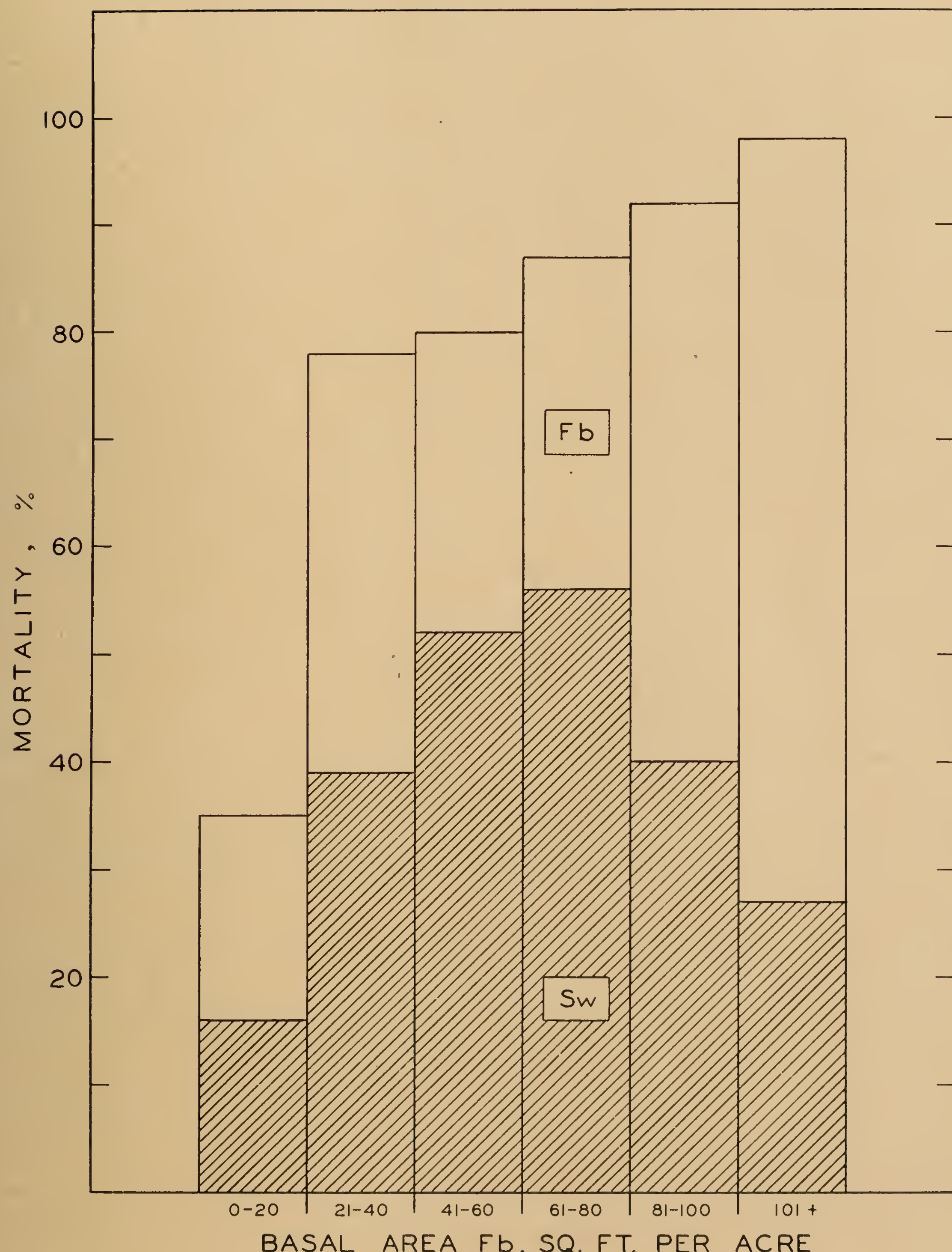

Fig. 14.—Average percentage mortality of fir and white spruce by basal area classes of fir in softwood types from the areas where over-all degree of fir mortality was moderately high.

Furthermore, the degree of white spruce mortality varied directly with the amount of white spruce per acre (Fig. 16 and Table 19). Highest mortality of white spruce occurred in plots where basal area of white spruce was 41 sq. ft. or more per acre, and most of these were characterized by a fir content of 61 to 80 sq. ft. basal area per acre. Therefore, highest white spruce mortality occurred in heaviest concentrations of spruce, where fir concentration was moderately high, and where fir mortality was 87 per cent (Fig. 14). Carrying this line of thought to its ultimate conclusion, it seems probable that if white spruce dominated the site, and little fir occurred, mortality of spruce and also of balsam fir would tend to drop. There is a slight indication of this in Fig. 16. Spruce mortality started to level off and fir mortality started to drop at spruce concentrations of more than 40 sq. ft. per acre.

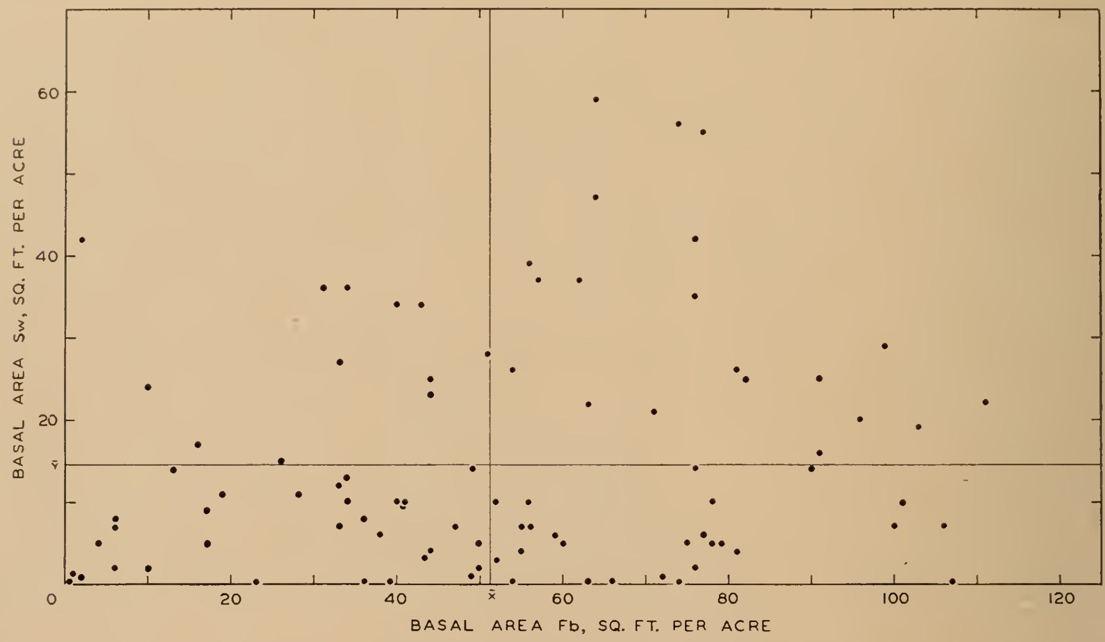

Fig. 15.—Relation of basal area of fir per acre to basal area of white spruce per acre in plots (1/10 acre or more in size) with softwood cover types from the areas where over-all degree of fir mortality was moderately high. Chi-square test of independence yielded a P value of ·13.

Fig. 17 illustrates fir mortality in plots from Table 19 classified by fir and by white-spruce content. The results show a tendency for balsam fir mortality, within defined limits of fir basal area per acre, to increase with white spruce basal area per acre. This is especially marked at lower categories of fir basal area, and confirms the trend of fir mortality shown in Fig. 16.

The degree of association between mortality of fir and basal area of fir was also determined by the Chi-square test of independence, and yielded a probability value of less than ·01 (Fig. 18).

To sum up, in softwood types there was good evidence that percentage mortality of fir increased with basal area of fir per acre.

(2) Mixedwood-softwood Types (SH)

Evidence of a relation between fir mortality and basal area of fir in SH types was weak (Table 20). By retaining control only of relative height of fir and total stand density, Table 21 gives some evidence of a gradual rise in percentage mortality of fir with increasing basal area of fir. When other variables were ignored and the data plotted in a scatter-diagram (Fig. 19) there was only slight and non-significant evidence of a relation between mortality and basal area (P = ·09).

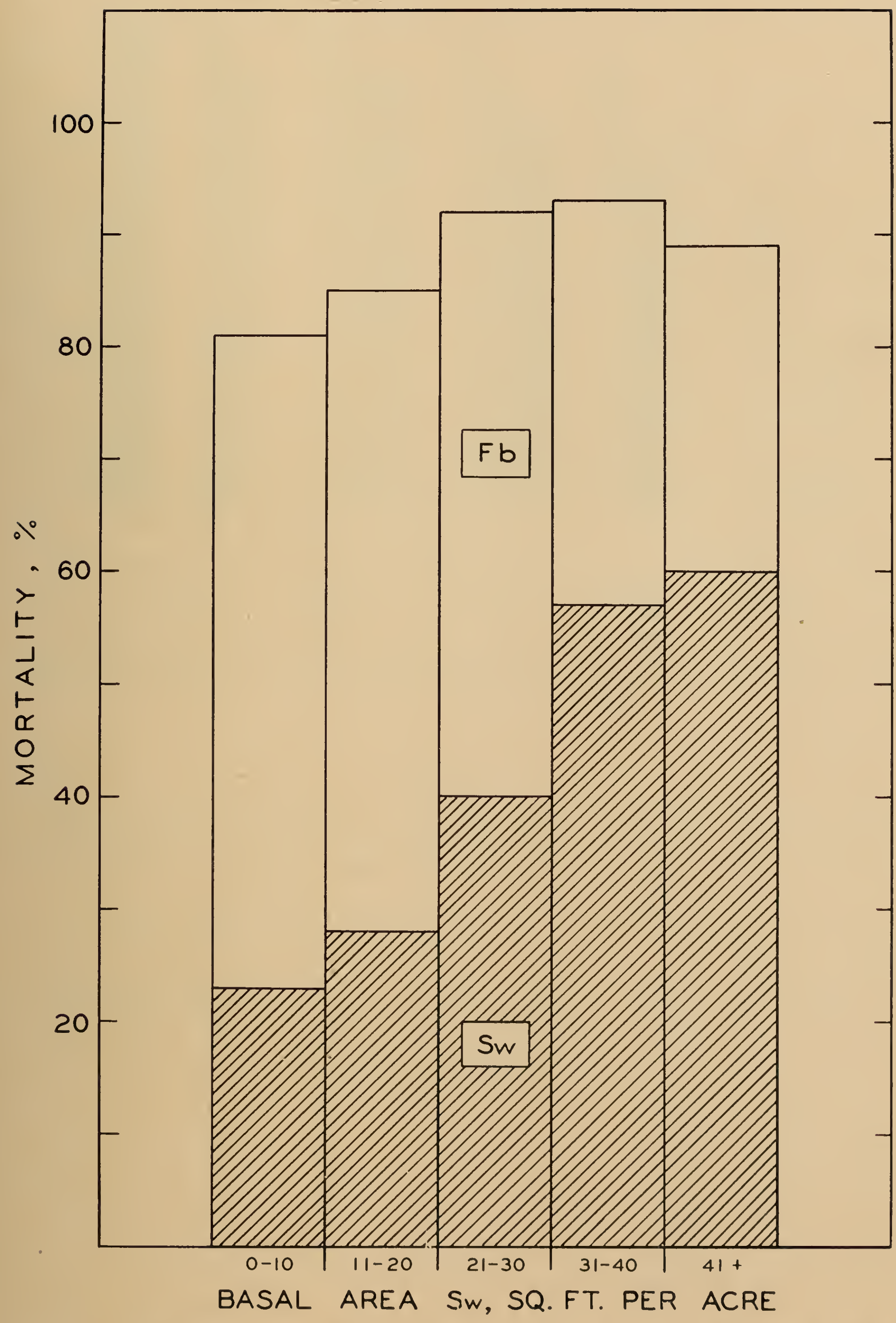

Fig. 16.—Average percentage mortality of fir and white spruce by basal area classes of white spruce in plots with softwood cover types from the areas where over-all degree of fir mortality was moderately high.

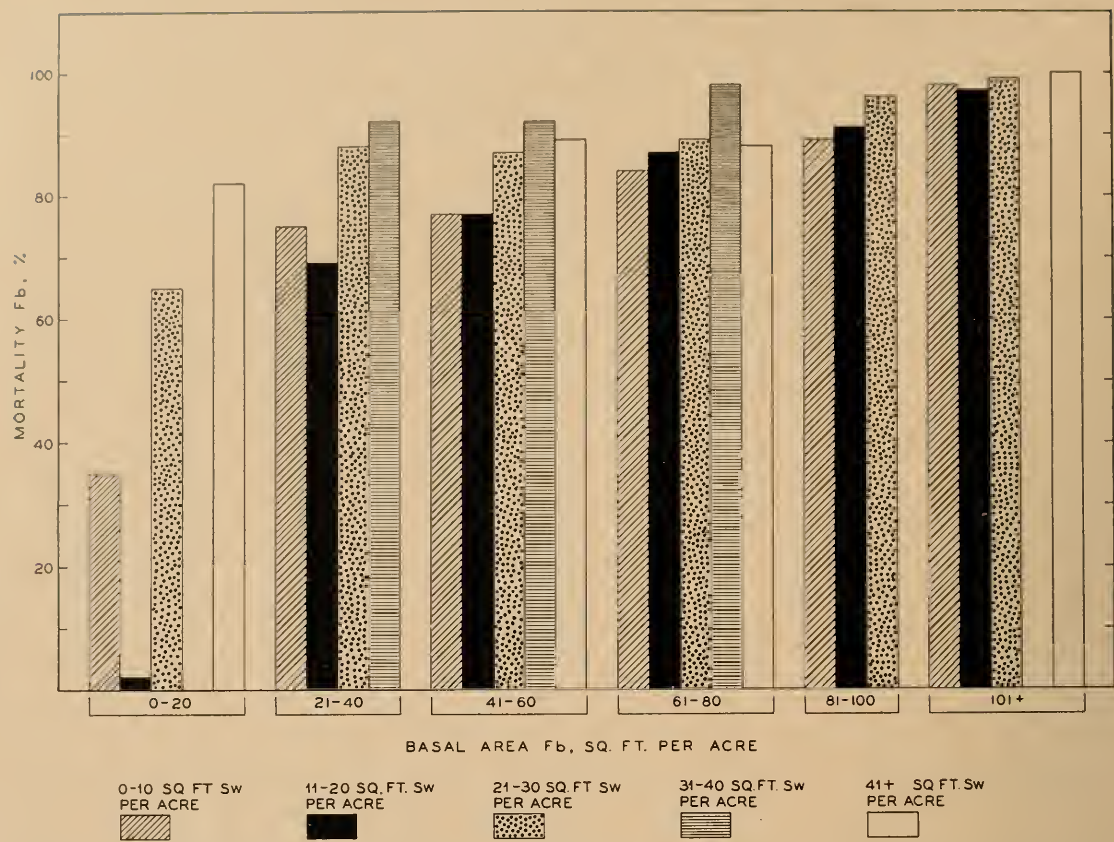

Fig. 17.—Percentage mortality of fir in plots classified by basal area of fir and white spruce per acre, for all softwood types from the areas where over-all degree of fir mortality was moderately high.

TABLE 20

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of Balsam Fir, with Control of Basal Area of White Spruce and of the Whole Stand, and of the Relative Height and Percentage Content of Fir

Broad Cover Type: Mixedwood-softwood (SH)

Variables Controlled within Indicated Limits				Basal Area of Fb										Trend
				0–20		21–40		41–60		61–80		81–100		
B.A. Sw	% Fb	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–10	41–60	51–100	CD	—	—	72	1	79	3	—	—	—	—	*
0–10	21–40	101–150	I	—	—	76	1	36	1	—	—	—	—	**
0–10	41–60	101–150	I	—	—	—	—	76	3	92	1	—	—	*
0–10	21–40	101–150	CD	—	—	82	2	94	1	—	—	—	—	*
0–10	41–60	101–150	CD	—	—	—	—	95	1	—	—	88	1	**
0–10	21–40	151–200	I	—	—	—	—	66	2	94	1	—	—	*
0–10	21–40	151–200	CD	—	—	—	—	—	—	100	2	85	3	**
0–10	21–40	201–250	I	—	—	—	—	56	1	81	2	—	—	*
11–20	21–40	151–200	CD	—	—	—	—	92	1	82	2	—	—	**
21–30	21–40	151–200	I	—	—	—	—	94	1	80	1	—	—	**
21–30	21–40	101–150	CD	—	—	47	1	92	1	—	—	—	—	*
31–40	21–40	151–200	I	—	—	—	—	72	2	99	1	—	—	*

	No.	%
Increasing mortality with increasing basal are of Fb (*)................	7	58
Decreasing mortality with increasing basal area of Fb (**).............	5	42
No trend..	0	
Total observations...	12	

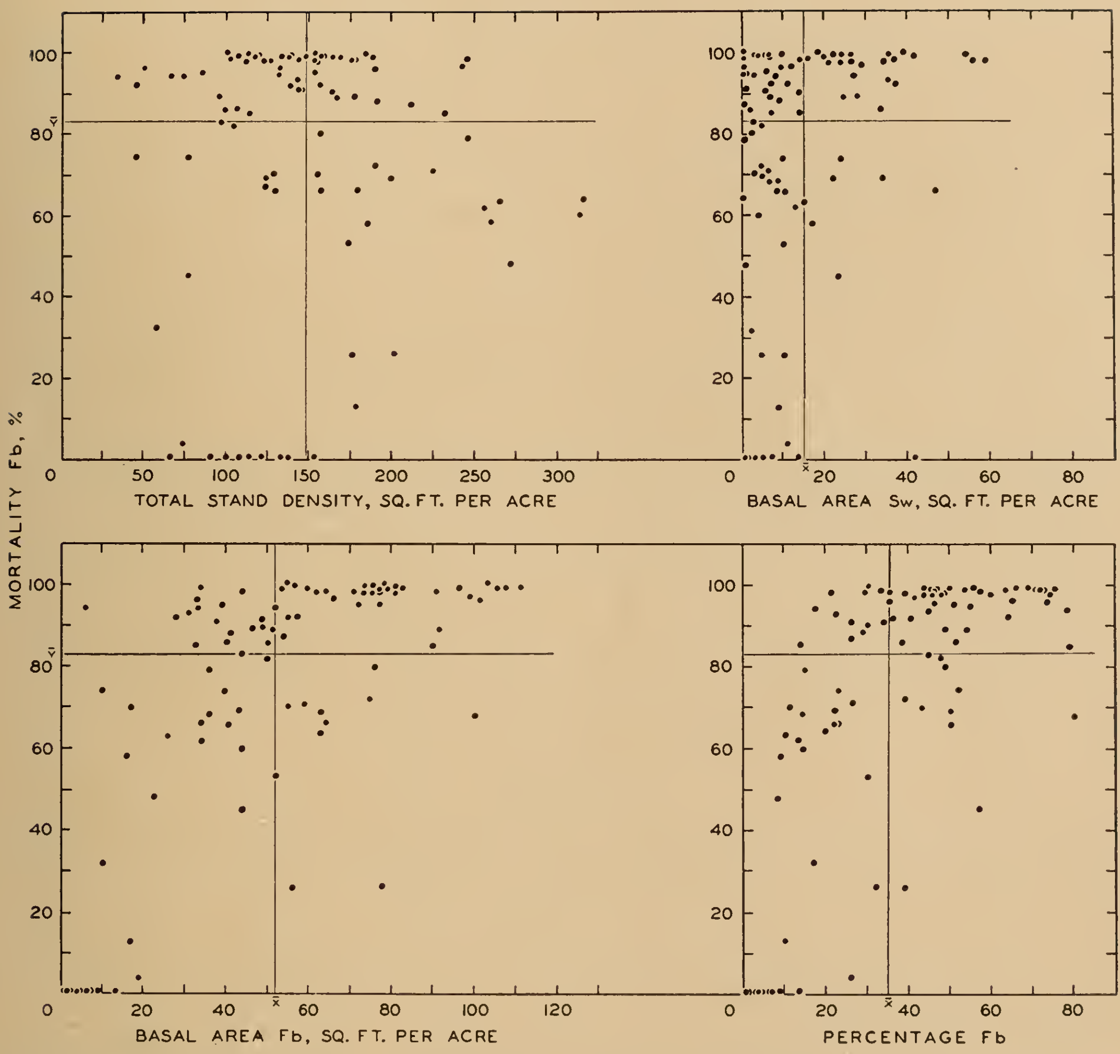

Fig. 18.—Percentage mortality of fir related to each of four variables, using plots (1/10 acre or more in size) with S cover types from the areas where over-all degree of fir mortality was moderately high. Chi-square test of independence gave the following P values:

Stand density and Fb mortality P= ·54
Basal area Sw and Fb mortality P= ·02
Basal area Fb and Fb mortality P=<·01
Percentage Fb and Fb mortality P=<·01

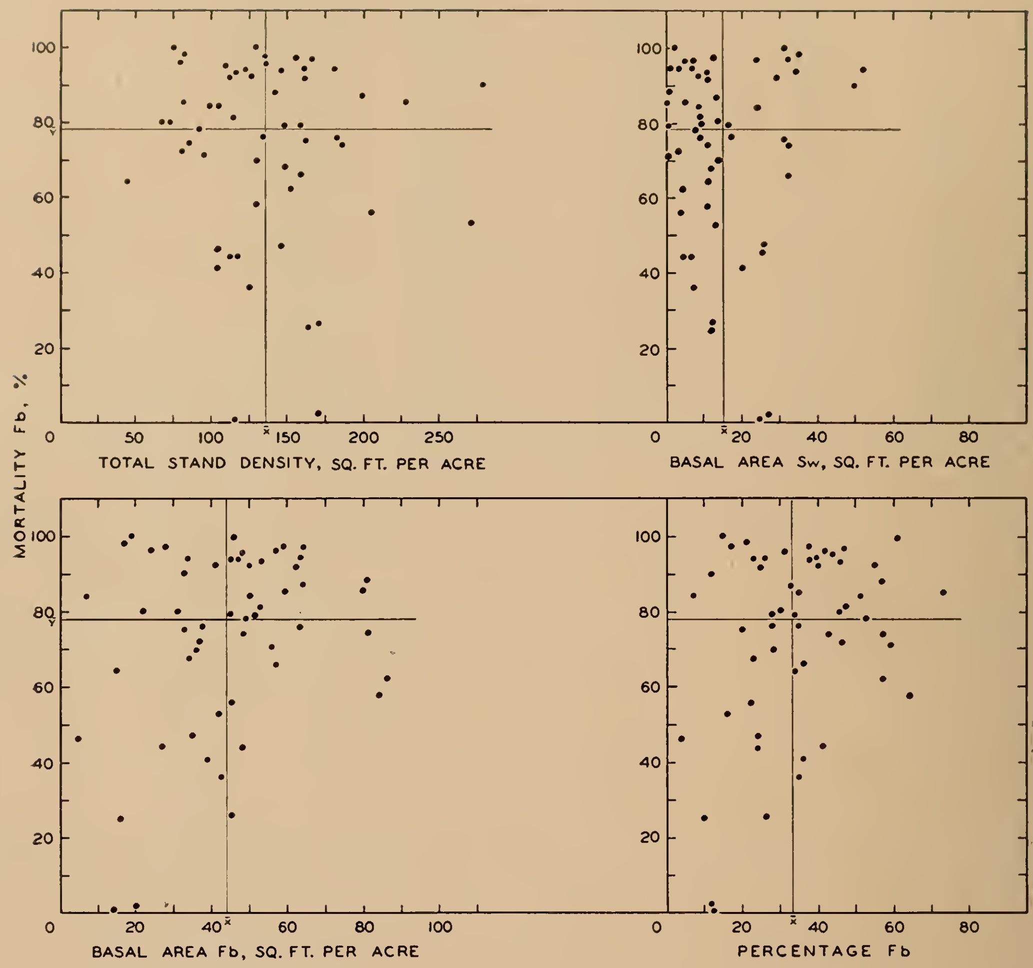

Fig. 19.—Percentage mortality of fir related to each of four variables, using plots (1/10 acre or more in size) with SH cover types from the areas where over-all degree of fir mortality was moderately high. Chi-square test of independence gave the following P values:

Stand density and Fb mortality P= ·88
Basal area Sw and Fb mortality P= ·99
Basal area Fb and Fb mortality P= ·09
Percentage Fb and Fb mortality P= ·40

TABLE 21

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area of Fir, with Control of Relative Height of Fir and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Rel. Ht. Fb	B.A. Stand	Basal Area of Fb																		Average Mort.		Total n
		0–20			21–40			41–60			61–80			81–100			101+					
		Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Mort. Fb	Sw	n	Fb	Sw	
CD	51–100	94	20	2	74	82	2	78	12	5	—	—	—	—	—	—	—	—	—	77	31	9
	101–150	71	86	4	73	20	4	91	28	4	97	32	1	66	33	4	—	—	—	82	43	17
	151–200	61	0	1	97	0	1	95	18	2	88	15	4	83	85	5	—	—	—	87	32	13
	201–250	—	—	—	—	—	—	66	0	1	88	8	1	—	—	—	—	—	—	81	7	2
	251–300	—	—	—	90	48	1	52	85	2	—	—	—	—	—	—	—	—	—	65	61	3
	Average	77	65	7	76	32	8	84	29	14	91	18	6	75	75	9	—	—	—	81	40	44
I	0–50	64	0	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64	0	1
	51–100	—	—	—	83	50	4	100	0	1	—	—	—	—	—	—	—	—	—	92	45	5
	101–150	—	—	—	67	29	4	80	28	5	92	0	1	—	—	—	—	—	—	77	27	10
	151–200	19	9	3	75	71	1	66	38	6	92	65	3	62	100	1	100	0	1	67	43	15
	201–250	—	—	—	—	—	—	56	0	1	73	68	3	82	0	1	—	—	—	72	55	5
	Average	30	7	4	71	42	9	77	32	13	85	54	7	69	71	2	100	0	1	75	37	36
U	51–100	—	—	—	96	18	1	—	—	—	—	—	—	—	—	—	—	—	—	96	18	1
	101–150	53	22	2	44	26	1	—	—	—	—	—	—	—	—	—	—	—	—	46	23	3
	Average	53	22	2	60	20	2	—	—	—	—	—	—	—	—	—	—	—	—	58	21	4
Total Average		58	46	13	74	33	19	80	30	27	88	34	13	74	75	11	100	0	1	79	37	84

TABLE 22

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of Balsam Fir, with Control of Basal Area of White Spruce and of the Whole Stand, and of the Relative Height and Percentage Content of Fir

Broad Cover Type: Mixedwood-hardwood (HS)

Variables Controlled within Indicated Limits				Basal Area of Fb										Trend
				0–20		21–40		41–60		61–80		81–100		
B.A. Sw	% Fb	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–10	0–20	101–150	I	67	2	48	2	—	—	—	—	—	—	**
0–10	21–40	101–150	I	—	—	44	3	69	1	—	—	—	—	*
0–10	21–40	101–150	CD	—	—	65	3	62	1	—	—	—	—	
0–10	21–40	151–200	I	—	—	59	2	79	3	70	1	—	—	*
11–20	21–40	51–100	CD	67	1	73	1	—	—	—	—	—	—	*
11–20	0–20	101–150	CD	45	1	47	1	—	—	—	—	—	—	
11–20	21–40	101–150	CD	—	—	78	2	54	1	—	—	—	—	**
11–20	0–20	101–150	I	8	1	42	1	—	—	—	—	—	—	*
11–20	0–20	101–150	U	71	1	43	1	—	—	—	—	—	—	**
21–30	0–20	101–150	I	0	1	50	1	—	—	—	—	—	—	*

	No.	%
Increasing mortality with increasing basal area of Fb (*).....	5	50
Decreasing mortality with increasing basal area of Fb (**)....	3	30
No trend..........	2	20
Total observations..........	10	

TABLE 23

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area, Percentage Content and Relative Height of Fir

Broad Cover Type: Mixedwood-hardwood (HS)

Rel. Ht. Fb	% Fb	Basal Area of Fb 0–20 Mort. Fb	Sw	n	21–40 Mort. Fb	Sw	n	41–60 Mort. Fb	Sw	n	61–80 Mort. Fb	Sw	n	Average Mort. Fb	Sw	Total n
CD	0–20	66	43	6	75	63	2	—	—	—	—	—	—	70	49	8
	21–40	67	0	1	74	36	11	69	14	5	—	—	—	72	29	17
	41–60	—	—	—	—	—	—	97	0	1	—	—	—	97	0	1
	Average	66	39	7	74	42	13	73	13	6	—	—	—	73	36	26
I	0–20	58	13	6	47	40	9	—	—	—	—	—	—	49	31	15
	21–40	75	0	2	44	46	7	70	43	5	73	44	4	61	51	18
	41–60	—	—	—	—	—	—	84	0	1	—	—	—	84	0	1
	Average	62	13	8	46	42	16	71	38	6	73	44	4	58	35	34
U	0–20	62	23	6	38	37	3	—	—	—	—	—	—	46	27	9
	21–40	—	—	—	62	32	4	90	0	1	—	—	—	67	31	5
	41–60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Average	62	23	6	54	34	7	90	0	1	—	—	—	59	28	14
Total Average		63	25	21	58	41	36	73	24	13	73	44	4	64	34	74

TABLE 24

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Percentage Fir Content, with Control of Relative Height of Fir, and of the Basal Areas of Fir, White Spruce and the Whole Stand

Broad Cover Type: Softwood

Variables Controlled Within Indicated Limits: B.A. Fb	B.A. Sw	B.A. Stand	Ht. Fb	Percentage Fb in Stand 0–20 Mort.	n	21–40 Mort.	n	41–60 Mort.	n	61–80 Mort.	n	81–100 Mort.	n	Trend
0–20	11–20	51–100	U	0	1	4	1	—	—	—	—	—	—	
21–40	0–10	151–200	I	91	3	66	1	—	—	—	—	—	—	**
21–40	21–30	51–100	I	—	—	68	1	90	2	—	—	—	—	*
41–60	0–10	51–100	CD	—	—	—	—	86	1	91	1	—	—	*
41–60	0–10	51–100	I	—	—	—	—	86	2	68	1	—	—	**
41–60	0–10	101–150	CD	—	—	—	—	99	1	94	1	—	—	**
41–60	0–10	101–150	I	—	—	77	3	72	2	—	—	—	—	**
41–60	0–10	201–250	CD	100	1	97	1	—	—	—	—	—	—	
41–60	21–30	101–150	CD	—	—	98	1	99	1	—	—	—	—	
61–80	0–10	101–150	I	—	—	—	—	71	2	100	1	—	—	*
61–80	0–10	151–200	I	—	—	95	1	96	2	—	—	—	—	
81–100	0–10	101–150	CD	—	—	—	—	76	1	70	2	100	1	*
101 +	0–10	101–150	CD	—	—	—	—	—	—	97	2	98	2	

	No.	%
Increasing mortality with increasing percentage Fb in stands (*)...	4	31
Decreasing mortality with increasing percentage Fb in stands (**)...	4	31
No trend..	5	38
Total observations..................................	13	

Therefore in SH types there was slight but inconclusive evidence that mortality of fir increased with basal area of fir.

(3) Mixedwood-hardwood Types (HS)

The successive analyses (Tables 22, 23) yielded unconvincing evidence of any relation between basal area of fir and fir mortality. When the data were

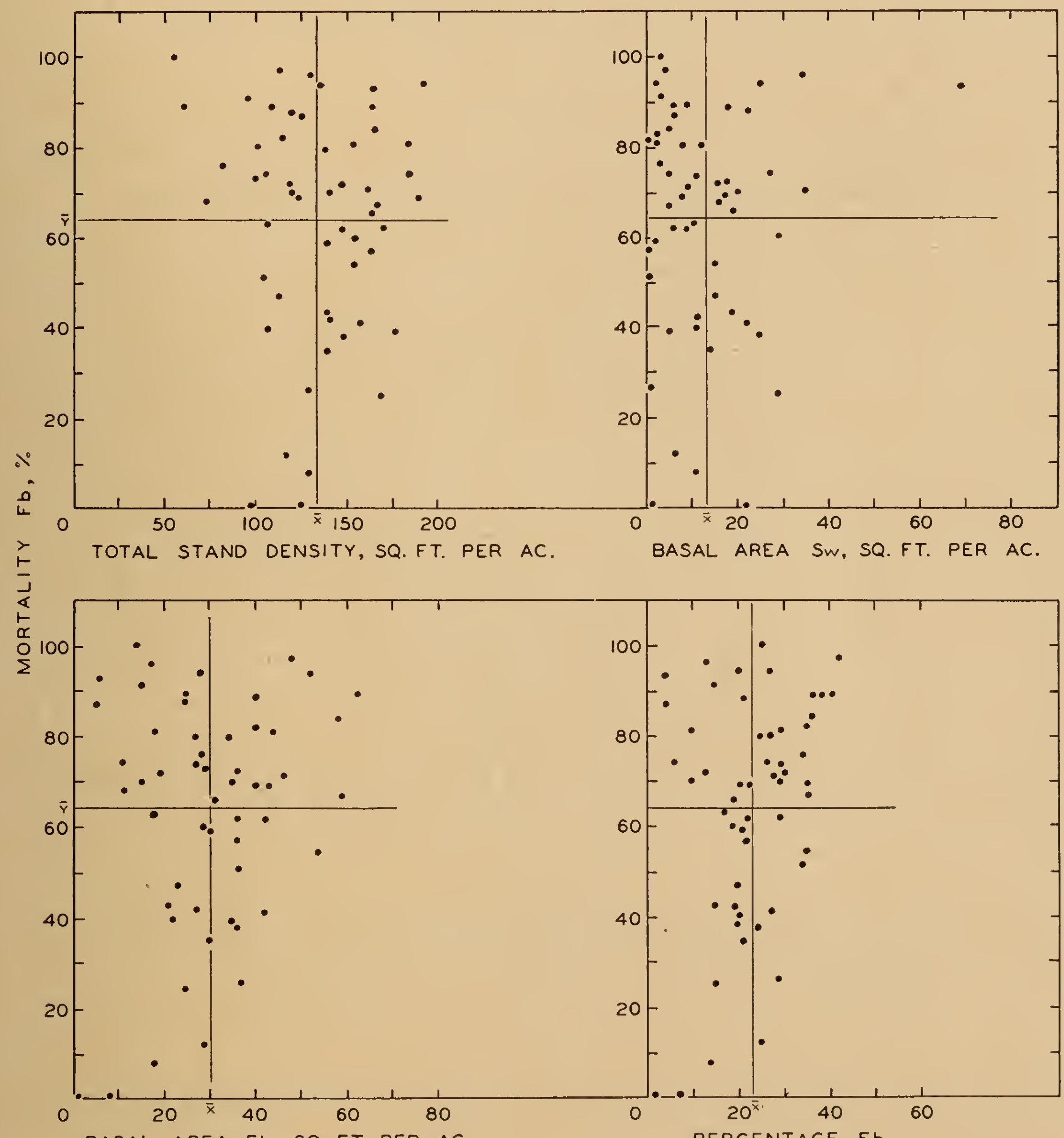

Fig. 20—Percentage mortality of fir related to each of four variables, using plots (1/10 acre or more in size) with HS cover types from the areas where over-all degree of fir mortality was moderately high. Chi-square test of independence gave the following P values:

Stand density and fir mortality P = ·79
Basal area Sw and fir mortality P = ·99
Basal area Fb and fir mortality P = ·99
Percentage Fb and fir mortality P = ·09

plotted without control of other variables (Fig. 20), the lack of relation was clearly evident (P = ·99).

The analysis for the effect of basal area of fir showed that as the proportion of hardwood increased, fir mortality and basal area of fir were less closely related.

Percentage of Balsam Fir

(1) Softwood Types (S)

Fir mortality and percentage of fir were apparently unrelated, when all variables were controlled (Table 24). When relative height of balsam fir and total stand density were disregarded in a broader analysis (Table 25), a tendency emerged for percentage mortality of fir to increase with proportion of fir in the stand. When the analysis was broadened still further (Fig. 18), there was a close degree of association between the two factors (P = < ·01).

TABLE 25

Percentage Mortality of Balsam Fir in Plots Segretated on the Basis of Percentage of Fir in Stands, with Control of Basal Area of Fir and of White Spruce

Broad Cover Type: Softwood

B.A. Fb	B.A. Sw	Percentage Fb in Stand										Trend
		0–20		21–40		41–60		61–80		81–100		
		Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	11–20	0	2	4	1	—	—	—	—	—	—	
0–20	21–30	54	2	74	1	—	—	—	—	—	—	*
21–40	0–10	74	10	82	2	74	4	—	—	—	—	
21–40	11–20	57	4	—	—	—	—	94	2	—	—	*
21–40	21–30	—	—	85	3	90	2	—	—	—	—	*
41–60	0–10	71	3	70	13	81	6	90	3	—	—	*
41–60	11–20	—	—	70	3	—	—	100	1	—	—	*
41–60	21–30	—	—	93	2	80	3	—	—	—	—	**
41–60	31–40	—	—	87	2	98	3	—	—	—	—	*
61–80	0–10	—	—	64	3	86	7	99	2	100	1	*
61–80	11–20	—	—	84	1	91	4	—	—	74	1	
61–80	21–30	—	—	98	2	68	1	—	—	—	—	**
61–80	31–40	—	—	99	1	98	1	—	—	—	—	
81–100	0–10	—	—	—	—	87	2	88	3	100	1	*
81–100	11–20	—	—	98	1	70	1	93	3	—	—	
101+	0–10	—	—	—	—	—	—	97	4	98	2	

	No.	%
Increasing mortality with increasing percentage Fb (*)	8	50
Decreasing mortality with increasing percentage Fb (**)	2	12
No trend	6	38
Total observations	16	

Although there appeared to be an association between fir mortality and percentage content of fir in softwood types, percentage of fir was dropped as a variable in favour of basal area of fir. This step was taken since basal area was correlated with percentage of fir (r = ·8, Fig. 21), and was more consistently related to fir mortality than was the percentage of fir.

(2) Mixedwood-softwood Types (SH)

Table 26 contains insufficient observations to draw a conclusion regarding the importance of percentage of fir in mixedwood-softwood types. When the analysis was broadened and only relative height of fir and total stand density were controlled (Table 27), the evidence of a relation between fir mortality and percentage content of fir was fairly weak, although there was an increase in mortality from the 0-20 to the 21-40 per cent classes. No relation between fir mortality and percentage of fir was evident in the scatter-diagram of the data (Fig. 19, P = ·40).

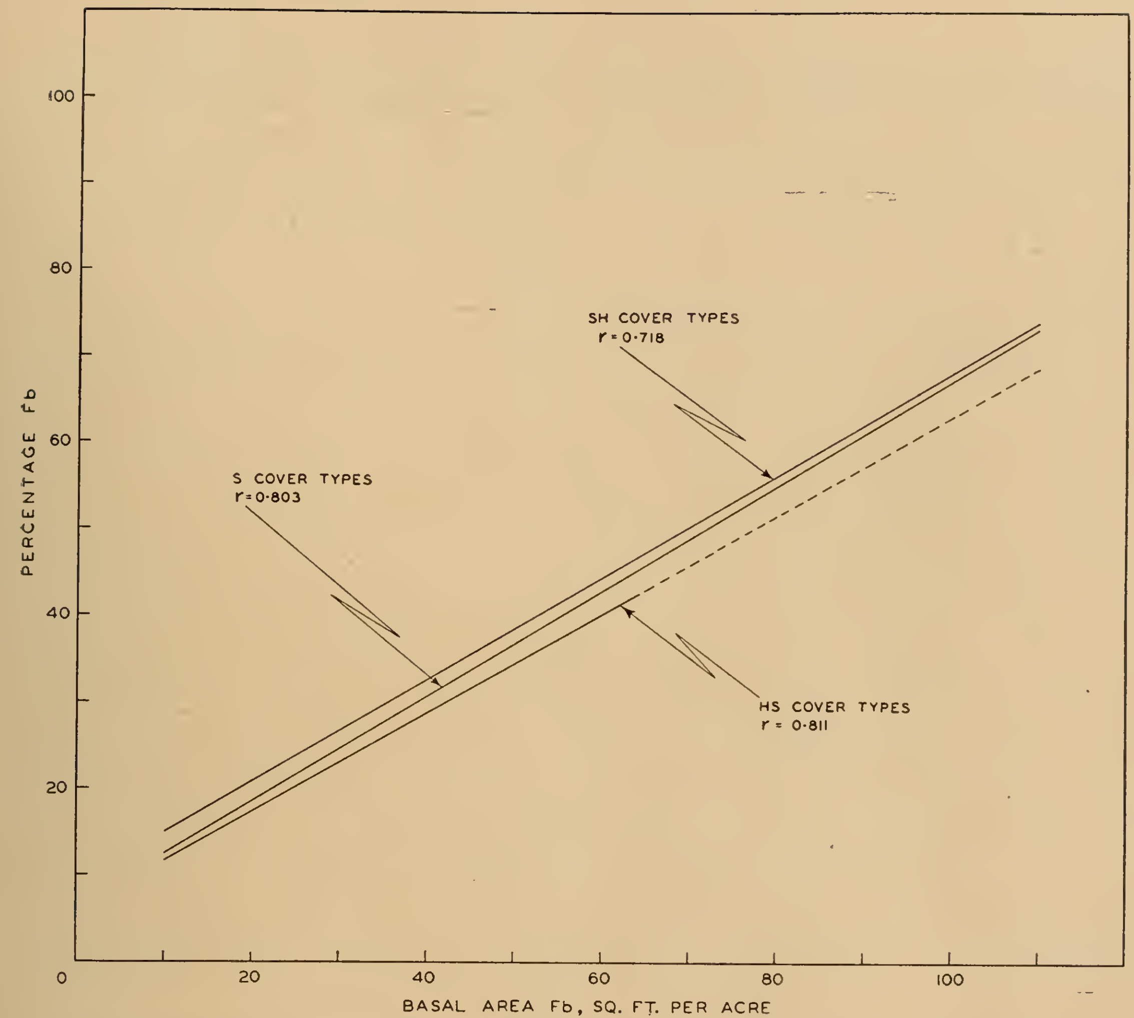

Fig. 21.—Regressions of percentage fir on basal area of fir in plots of the S, SH and HS broad cover types. The regressions were based on the following numbers of plots: S cover types—91; SH cover types—55; HS cover types—54.

TABLE 26

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Percentage Fir Content, with Control of Relative Height of Fir, and of the Basal Areas of Fir, White Spruce and the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Variables Controlled within Indicated Limits				Percentage Fb in Stand								Trend
				0–20		21–40		41–60		61–75		
B.A. Fb	B.A. Sw	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
21–40	0–10	51–100	I	—	—	93	1	80	1	—	—	**
21–40	0–10	51–100	CD	—	—	97	1	72	1	—	—	**
41–60	0–10	51–100	CD	—	—	—	—	79	3	85	1	*
41–60	0–10	101–150	I	—	—	36	1	76	3	—	—	*
41–60	0–10	101–150	CD	—	—	94	1	95	1	—	—	
81–100	0–10	101–150	CD	—	—	—	—	88	1	57	2	**

	No.	%
Increasing mortality with increasing percentage Fb in stand (*)...	2	33
Decreasing mortality with increasing percentage Fb in stand (**).	3	50
No trend..........	1	17
Total observations..........	6	

TABLE 27

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Percentage of Fir in Stands, with Control of Relative Height of Fir, and Total Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Rel. Ht. Fb	B.A. Stand	Percentage Fb in Stand											
		0–20			21–40			41–60			61–75		
		Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n
CD	51–100	75	0	1	97	24	2	75	37	5	85	—	1
	101–150	71	86	4	85	24	7	94	35	3	57	31	3
	151–200	84	0	2	88	18	4	86	71	7	—	—	—
	201–250	66	0	1	88	8	1	—	—	—	—	—	—
	251–300	65	61	3	—	—	—	—	—	—	—	—	—
	Average	71	64	11	87	22	14	83	48	15	64	31	4
I	0–50	—	—	—	64	0	1	—	—	—	—	—	—
	51–100	—	—	—	86	69	3	80	0	1	100	0	1
	101–150	—	—	—	63	28	5	86	26	5	—	—	—
	151–200	41	33	4	75	46	9	62	100	1	100	0	1
	201–250	—	—	—	69	60	4	82	0	1	—	—	—
	Average	41	33	4	70	43	22	82	27	8	100	0	2
U	51–100	—	—	—	96	18	1	—	—	—	—	—	—
	101–150	53	22	2	44	26	1	—	—	—	—	—	—
	Average	53	22	2	60	20	2	—	—	—	—	—	—
Total Average		62	52	17	78	30	38	82	40	23	74	22	6

TABLE 28

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Percentage Fir Content, with Control of Relative Height of Fir, and of the Basal Area of Fir, White Spruce and the Whole Stand

Broad Cover Type: Mixedwood-hardwood (HS)

Variables Controlled within Indicated Limits				Percentage Fb in Stand						Trend
				0–20		21–40		41–50		
B.A. Fb	B.A. Sw	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	
0–20	0–10	51–100	I	91	1	99	1	—	—	*
21–40	0–10	101–150	I	48	2	44	3	—	—	
21–40	0–10	151–200	I	68	1	59	2	—	—	**
21–40	11–20	101–150	U	43	1	71	1	—	—	*
21–40	11–20	101–150	I	42	1	35	1	—	—	**
21–40	11–20	101–150	CD	47	1	78	2	—	—	*
21–40	21–30	101–150	I	50	1	38	1	—	—	**
21–40	21–30	101–150	CD	94	1	88	1	—	—	**
41–60	0–10	101–150	CD	—	—	62	1	97	1	*

	No.	%
Increasing mortality with increasing percentage Fb in stand (*)...	4	44
Decreasing mortality with increasing percentage Fb in stand (**).	4	44
No trend..	1	11
Total observations...	9	

(3) Mixedwood-hardwood Types (HS)

In the detailed tabular analysis (Table 28), the percentage of fir was apparently unrelated to fir mortality. When all variables were ignored except relative height of fir and stand density (Table 29), the fir mortality tended to increase with the percentage of fir. In the scatter-diagram of the data (Fig. 20), there was inconclusive evidence of an increase in fir mortality with the percentage of fir (P = ·09).

TABLE 29

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Percentage Fir Content, with Control of Relative Height of Fir and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-hardwood (HS)

Rel. Ht. Fb	B.A. Stand	Percentage Fb in Stand					
		0–20		21–40		41–50	
		Mort.	n	Mort.	n	Mort.	n
CD	51–100	0	1	76	5	—	—
	101–150	69	5	68	8	97	1
	151–200	78	2	75	4	—	—
	Average	70	8	72	17	97	1
I	0–50	—	—	51	1	—	—
	51–100	91	1	99	1	—	—
	101–150	47	9	44	6	84	1
	151–200	49	5	72	9	—	—
	251–300	—	—	42	1	—	—
	Average	49	15	61	18	84	1
U	51–100	55	3	—	—	—	—
	101–150	50	3	61	4	—	—
	151–200	41	3	—	—	—	—
	201–250	—	—	90	1	—	—
	Average	46	9	67	5	—	—

The replacement of basal area of fir by percentage of fir as a possibly influential variable in this type is of considerable interest. It is important to emphasize that the distinction was not merely the result of cover type definitions, because in all three cover types there was a strong and very similar correlation between basal area and percentage of fir (Fig. 21).

TABLE 30

Distribution of Plots by Relative Height of Fir, and by Above-average or Below-average Mortality of Fir Compared with the Mean for the Group of Plots of Similar Detailed Cover Type and Percentage of Fir

Locality		Above-average Mortality			Below-average Mortality		
		Relative Height of Fb			Relative Height of Fb		
		U	I	CD	U	I	CD
Mississagi River............	n	12	112	56	25	82	18
	%	32	58	76	—	—	—
Michipicoten R.—Manitowik L................	n	14	32	21	17	37	13
	%	45	46	62	—	—	—

Relative Height of Balsam Fir

In a qualitative preliminary analysis (Table 30), there was evidence that, in areas of high over-all fir mortality, the mortality of fir was below average in stands where the fir was understory, and was above average where fir occurred in the co-dominant class. Illustrating for the Mississagi area in Table 30, above-average mortality of fir occurred in only 32 per cent of the plots where fir was not higher than the understory height class, and occurred in 76 per cent of the plots in which fir reached the co-dominant class. These observations are supplemented by the following more adequate quantitative analysis.

(1) Softwood Types (S)

The data in Table 31 show a tendency for fir mortality to increase with relative height of fir when all variables are controlled. This tendency is particularly noticeable until concentrations of fir reach about 60 sq. ft. per acre. In a broader analysis (Table 19) the effect of relative height was more clearly shown; viz., increase in mortality with relative height in the lower classes of basal area of balsam fir and of white spruce, and the reverse relation in the higher classes of basal area. To determine the effect of relative height on fir mortality without control of any other factors, the data were compiled in a 2 x 3 contingency table and the degree of association determined by the Chi-square test of independence. The result showed a high degree of association (P = < ·01) between fir mortality and relative height of fir.

TABLE 31

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Relative Height of Fir, with Control of Basal Area and Percentage of Fir, Basal Area of White Spruce and Basal Area of the Whole Stand

Broad Cover Type: Softwood

Variables Controlled within Indicated Limits				Relative Height of Fb						Trend
				U		I		CD		
B.A. Fb	% Fb	B.A. Sw	B.A. Stand	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	0–10	151–200	10	2	70	1	—	—	*
0–20	0–20	41+	101–150	100	1	99	1	—	—	
21–40	0–20	0–10	151–200	70	1	91	3	—	—	*
21–40	0–20	11–20	251–300	—	—	15	1	62	2	*
21–40	21–40	21–30	101–150	90	1	—	—	100	1	*
21–40	21–40	31–40	101–150	93	1	91	4	—	—	
21–40	41–60	0–10	51–100	18	1	81	3	—	—	*
21–40	61–80	11–20	0–50	—	—	96	1	92	1	
41–60	21–40	0–10	151–200	26	1	77	4	58	1	
41–60	21–40	0–10	201–250	71	1	66	2	97	1	*
41–60	21–40	31–40	151–200	—	—	92	1	70	1	**
41–60	41–60	0–10	51–100	—	—	86	1	86	1	
41–60	41–60	0–10	101–150	—	—	72	2	99	1	*
41–60	41–60	21–30	101–150	—	—	98	1	99	1	
41–60	61–80	0–10	51–100	—	—	68	1	91	1	*
61–80	21–40	0–10	151–200	72	1	95	1	—	—	*
61–80	41–60	0–10	101–150	—	—	71	2	96	2	*
61–80	41–60	0–10	151–200	—	—	96	2	80	1	**
61–80	41–60	11–20	151–200	—	—	86	1	98	1	*
61–80	41–60	41+	101–150	—	—	91	4	0	1	**
81–100	41–60	21–30	151–200	—	—	98	1	94	2	
81–100	61–80	0–10	101–150	—	—	99	1	70	2	**
81–100	61–80	11–20	101–150	—	—	99	1	90	2	**

	No.	%
Increasing mortality with increasing rel. ht. of Fb (*)	11	48
Decreasing mortality with increasing rel. ht. of Fb (**)	5	22
No trend	7	30
Total observations	23	

(2) In Mixedwood-softwood Types (SH)

Table 32 reveals a fairly strong trend of increasing mortality with increasing relative height of fir. In Table 21, where some variables are ignored, there is also an increase in fir mortality with an increase in relative height, both within comparable stand density groups, and for the broad average when stand density is ignored. The only exception is where the stand density is very low (51 to 100 sq. ft. per acre). When all data were combined and entered in a contingency table, the resulting test for independence gave a P value of ·06.

TABLE 32

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Relative Height of Fir, with Control of Basal Area and Percentage of Fir, Basal Area of White Spruce and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Variables Controlled within Indicated Limits				Relative Height of Fb						Trend
				U		I		CD		
B.A. Fb	% Fb	B.A. Sw	B.A. Stand	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	0–10	151–200	—	—	43	1	61	1	*
0–20	0–20	21–30	101–150	47	1	—	—	29	2	**
0–20	0–20	31–40	101–150	57	1	—	—	100	1	*
21–40	0–20	31–40	151–200	—	—	75	1	97	1	*
21–40	21–40	0–10	101–150	44	1	76	1	82	2	*
21–40	21–40	0–10	51–100	—	—	93	1	97	1	
21–40	41–60	0–10	51–100	—	—	80	1	72	1	**
41–60	21–40	0–10	101–150	—	—	36	1	94	1	*
41–60	21–40	11–20	151–200	—	—	26	1	92	1	*
41–60	21–40	21–30	151–200	—	—	94	1	97	1	
41–60	41–60	0–10	101–150	—	—	76	3	95	1	*
41–60	61–80	0–10	51–100	—	—	100	1	85	1	**
81–100	41–60	0–10	151–200	—	—	62	1	85	3	*

	No.	%
Increasing mortality with increasing rel. ht. of Fb (*).........	8	62
Decreasing mortality with increasing rel ht. of Fb (**).......	3	23
No trend..	2	15
Total observations..	13	

(3) Mixedwood-hardwood Types (HS)

The degree of fir mortality in these types was only slightly affected by relative height (Table 33). In a broader analysis (Table 23) the result was similar, except that the mortality was considerably greater in plots containing co-dominant fir, than in plots with only intermediate or understory fir. In a Chi-square test of the independence of the two variables, the probability value was ·05.

Basal Area of White Spruce

(1) Softwood Types (S)

There was a tendency for fir mortality to increase with the basal area of white spruce when all associated variables were controlled (Table 34). This was confirmed when the analysis was broadened and only basal area and relative height of fir were controlled (Table 19), and when the data were plotted in a scatter-diagram (Fig. 18, P = ·02).

(2) Mixedwood-softwood Types (SH)

The successive analyses (Tables 35, 36) gave no evidence of a relation between basal area of white spruce and mortality of fir in SH types. When the data were plotted without control of other variables (Fig. 19), the lack of a relation was clearly evident (P = ·99).

TABLE 33

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Relative Height of Fir, with Control of Basal Area and Percentage of Fir, Basal Area of White Spruce and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-hardwood (HS)

Variables Controlled within Indicated Limits				Relative Height of Fb						Trend
				U		I		CD		
B.A. Fb	% Fb	B.A. Sw	B.A. Stand	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	0–10	51–100	0	2	91	1	—	—	*
0–20	0–20	0–10	101–150	0	1	67	2	63	1	*
0–20	0–20	11–20	101–150	71	1	8	1	45	1	
0–20	0–20	31–40	101–150	—	—	96	1	70	1	**
21–40	0–20	0–10	151–200	39	1	68	1	—	—	*
21–40	0–20	11–20	101–150	43	1	42	1	47	1	
21–40	0–20	21–30	101–150	—	—	50	1	94	1	*
21–40	0–20	21–30	151–200	23	1	42	2	—	—	*
21–40	21–40	0–10	101–150	58	3	44	3	65	3	
21–40	21–40	11–20	101–150	71	1	35	1	78	2	
21–40	21–40	21–30	101–150	—	—	38	1	88	1	*
41–60	21–40	0–10	101–150	—	—	69	1	62	1	**
41–60	21–40	0–10	151–200	—	—	79	3	76	3	

	No.	%
Increasing mortality with increasing rel. ht. of Fb (*)	6	46
Decreasing mortality with increasing rel ht. of Fb (**)	2	15
No trend	5	39
Total observations	13	

TABLE 34

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of White Spruce, with Control of Relative Height, Percentage Content and Basal Area of Fir, and Basal Area of the Whole Stand

Broad Cover Type: Softwood

Variables Controlled within Indicated Limits				Basal Area of Sw										Trend
				0–10		11–20		21–30		31–40		41+		
B.A. Fb.	% Fb	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	101–150	U	0	3	—	—	—	—	—	—	100	1	*
0–20	0–20	201–250	U	56	1	—	—	0	1	—	—	—	—	**
21–40	0–20	251–300	I	58	3	15	1	—	—	—	—	—	—	**
21–40	21–40	101–150	I	91	1	—	—	—	—	91	4	—	—	
21–40	21–40	101–150	U	—	—	—	—	90	1	93	1	—	—	
21–40	41–60	51–100	I	81	3	—	—	90	2	—	—	—	—	*
41–60	21–40	151–200	CD	58	1	—	—	—	—	70	1	89	3	*
41–60	21–40	151–200	I	77	4	84	2	89	1	92	1	—	—	*
41–60	41–60	101–150	I	72	2	—	—	98	1	98	3	—	—	*
41–60	41–60	101–150	CD	99	1	—	—	99	1	—	—	—	—	
41–60	41–60	51–100	CD	86	1	—	—	45	1	—	—	—	—	**
41–60	61–80	51–100	CD	91	1	100	1	—	—	—	—	—	—	*
61–80	21–40	151–200	I	95	1	—	—	—	—	99	1	—	—	
61–80	21–40	251–300	I	—	—	84	1	97	1	—	—	—	—	*
61–80	41–60	151–200	CD	80	1	98	1	—	—	—	—	98	2	*
61–80	41–60	101–150	CD	96	2	—	—	—	—	98	1	0	1	
61–80	41–60	101–150	I	71	2	87	2	68	1	—	—	91	4	*
61–80	41–60	151–200	I	96	2	86	1	—	—	—	—	—	—	**
61–80	81–100	51–100	CD	100	1	74	1	—	—	—	—	—	—	**
81–100	41–60	151–200	CD	—	—	70	1	94	2	—	—	—	—	*
81–100	41–60	151–200	I	98	1	—	—	98	1	—	—	—	—	
81–100	61–80	101–150	CD	70	2	90	2	—	—	—	—	—	—	*
81–100	61–80	101–150	I	99	1	99	1	—	—	—	—	—	—	
101+	61–80	151–200	I	98	2	—	—	99	1	—	—	—	—	

	No.	%
Increasing mortality with increasing basal area of Sw (*)	11	46
Decreasing mortality with increasing basal area of Sw (**)	5	21
No trend	8	33
Total observations	24	

TABLE 35

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of White Spruce, with Control of Relative Height, Percentage Content and Basal Area of Fir, and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Variables Controlled within Indicated Limits				Basal Area of Sw										Trend
				0–10		11–20		21–30		31–40		41+		
B.A. Fb	% Fb	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	151–200	I	43	1	25	1	2	1	—	—	—	—	**
0–20	0–20	101–150	CD	—	—	—	—	29	2	100	1	—	—	*
0–20	0–20	101–150	U	—	—	—	—	47	1	57	1	—	—	*
21–40	21–40	101–150	CD	82	2	—	—	47	1	—	—	94	1	
21–40	21–40	51–100	I	93	1	80	1	85	1	—	—	—	—	
21–40	21–40	101–150	I	76	1	63	3	—	—	—	—	—	—	**
41–60	0–20	251–300	CD	—	—	53	1	51	1	—	—	—	—	
41–60	21–40	151–200	I	66	2	26	1	94	1	72	2	—	—	*
41–60	21–40	151–200	CD	—	—	92	1	97	1	—	—	—	—	*
41–60	21–40	101–150	CD	94	1	79	1	92	1	—	—	—	—	
41–60	41–60	101–150	I	76	3	93	1	—	—	—	—	—	—	*
41–60	41–60	51–100	CD	79	3	74	1	—	—	—	—	—	—	**
61–80	21–40	201–250	I	81	2	—	—	—	—	—	—	52	1	**
61–80	21–40	151–200	I	94	1	—	—	80	1	99	1	—	—	
81–100	41–60	151–200	CD	85	3	—	—	87	1	74	1	—	—	**
81–100	61–80	101–150	CD	57	2	58	1	—	—	—	—	—	—	

	No.	%
Increasing mortality with increasing basal area of Sw (*).....	5	31
Decreasing mortality with increasing basal area of Sw (**)...	5	31
No trend..	6	38
Total observations..	16	

TABLE 36

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area of White Spruce, with Control of Relative Height of Fir, and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Relative Height Fb	B.A. Stand	Basal Area of Sw														
		0–10			11–20			21–30			31–40			41+		
		Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n	Mort. Fb	Mort. Sw	n
CD	51–100	77	47	7	74	20	1	—	—	—	98	21	1	—	—	—
	101–150	84	27	6	81	18	3	75	47	4	100	100	1	94	26	1
	151–200	88	8	6	85	12	3	94	45	2	80	49	2	—	—	—
	201–250	66	0	1	—	—	—	—	—	—	88	8	1	—	—	—
	251–300	—	—	—	53	70	1	51	98	1	—	—	—	90	48	1
	Average	82	33	20	79	20	8	80	49	7	87	48	5	92	35	2
I	0–50	—	—	—	64	0	1	—	—	—	—	—	—	—	—	—
	51–100	94	5	3	80	69	1	85	83	1	—	—	—	—	—	—
	101–150	76	24	6	79	28	4	—	—	—	—	—	—	—	—	—
	151–200	70	75	5	26	37	2	71	15	3	80	60	4	—	—	—
	201–250	76	0	4	—	—	—	—	—	—	—	—	—	52	81	1
	Average	77	22	18	71	31	8	73	24	4	80	60	4	52	81	1
U	51–100	—	—	—	—	—	—	—	—	—	96	18	1	—	—	—
	101–150	44	26	1	—	—	—	47	28	1	57	11	1	—	—	—
	Average	44	26	1	—	—	—	47	28	1	84	15	2	—	—	—
Total Average		79	27	39	76	26	16	78	41	12	84	47	11	79	42	3

Table 36 further shows that in these types the white-spruce content did not influence the percentage mortality of white spruce in a consistent manner. Except occasionally, the mortality of white spruce was extremely variable and void of any trends, a condition which may have resulted from the low quantities of white spruce usually encountered.

(3) Mixedwood-hardwood Types (HS)

When all variables were controlled (Table 37), there was no evidence of a relation between fir mortality and basal area of white spruce. When the less important variables were ignored (Table 38), there was an indication of a decrease in fir mortality with an increase in white-spruce content, up to spruce

TABLE 37

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of White Spruce, with Control of Relative Height, Percentage Content and Basal Area of Fir, and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-hardwood (HS)

Variables Controlled within Indicated Limits				Basal Area of Sw										Trend
				0–10		11–20		21–30		31–40		41+		
B.A. Fb	% Fb	B.A. Stand	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	101–150	CD	63	1	45	1	—	—	70	1	—	—	
0–20	0–20	101–150	I	67	2	8	1	0	1	96	1	—	—	
0–20	0–20	151–200	CD	81	1	—	—	74	1	—	—	—	—	**
0–20	0–20	51–100	U	0	2	68	1	—	—	—	—	—	—	*
0–20	0–20	101–150	U	0	1	71	1	—	—	—	—	—	—	*
21–40	0–20	151–200	I	68	1	66	1	42	2	—	—	52	1	**
21–40	0–20	101–150	I	48	2	42	1	50	1	—	—	—	—	
21–40	0–20	101–150	CD	47	1	94	1	—	—	—	—	—	—	*
21–40	0–20	151–200	U	39	1	—	—	23	1	—	—	—	—	**
21–40	21–40	51–100	CD	81	3	73	1	—	—	—	—	—	—	**
21–40	21–40	101–150	CD	65	3	78	2	88	1	—	—	—	—	*
21–40	21–40	101–150	I	44	3	35	1	38	1	—	—	—	—	
21–40	21–40	101–150	U	58	3	71	1	—	—	—	—	—	—	*
41–60	21–40	101–150	CD	62	1	54	1	—	—	—	—	—	—	**
41–60	21–40	151–200	I	79	3	—	—	41	1	—	—	—	—	**
61–80	21–40	151–200	I	70	2	89	1	—	—	—	—	—	—	*

	No.	%
Increasing mortality with increasing basal area of Sw (*).....	6	38
Decreasing mortality with increasing basal area of Sw (**)...	6	38
No trend..	4	25
Total observations..	16	

TABLE 38

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area of White Spruce, with Control of Relative Height of Fir

Broad Cover Type: Mixedwood-hardwood (HS)

Rel. Ht. Fb	Basal Area of Sw														
	0–10			11–20			21–30			31–40			41+		
	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n
CD	74	20	13	68	48	8	89	45	3	62	17	2	—	—	—
I	65	38	20	58	24	6	39	40	6	96	19	1	52	100	1
U	59	17	8	62	30	4	23	0	1	—	—	—	94	35	1
Average	68	26	41	63	35	18	50	40	10	83	18	3	63	52	2

concentrations of about 30 sq. ft. per acre. The plots in which white spruce occurred at 31 sq. ft. or more per acre destroy the trend, and on the whole the data in Table 38 do not give much evidence of an influence of white-spruce content on degree of fir mortality. This result was also obtained when no variables were controlled (Fig. 20, P = ·99).

Basal Area of Whole Stand

(1) Softwood Types (S)

There was no evidence of fir mortality being affected by total stand density in the softwood types. This observation was supported by the data when all variables were controlled (Table 39); when only the more important variables were controlled (Table 40); and when all other variables were uncontrolled (Fig. 18, P = ·54).

TABLE 39

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of the Whole Stand, with Control of Basal Area, Percentage and Relative Height of Fir, and Basal Area of White Spruce

Broad Cover Type: Softwood

Variables Controlled within Indicated Limits				Basal Area of Whole Stand										Trend
				51–100		101–150		151–200		201–250		251–300		
B.A. Fb	% Fb	B.A. Sw	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	0–10	U	20	2	0	3	10	2	56	1	—	—	
21–40	0–20	0–10	I	—	—	—	—	91	3	83	3	58	3	**
21–40	0–20	11–20	CD	—	—	—	—	84	1	—	—	62	2	**
21–40	21–40	0–10	I	—	—	91	1	66	1	—	—	—	—	**
41–60	21–40	0–10	CD	—	—	—	—	58	1	97	1	—	—	*
41–60	21–40	0–10	I	—	—	77	3	77	4	66	2	—	—	**
41–60	21–40	0–10	U	—	—	—	—	26	1	71	1	—	—	*
41–60	41–60	0–10	CD	86	1	99	1	—	—	—	—	—	—	*
41–60	41–60	0–10	I	86	2	72	2	—	—	—	—	—	—	**
41–60	41–60	21–30	CD	45	1	99	1	—	—	—	—	—	—	*
41–60	61–80	0–10	CD	91	1	94	1	—	—	—	—	—	—	
61–80	21–40	0–10	I	—	—	—	—	95	1	26	1	—	—	**
61–80	41–60	0–10	CD	—	—	96	2	80	1	—	—	—	—	**
61–80	41–60	0–10	I	—	—	71	2	96	2	—	—	—	—	*
61–80	41–60	11–20	I	—	—	87	2	86	1	—	—	—	—	
61–80	41–60	41+	CD	—	—	0	1	98	2	—	—	—	—	*
61–80	61–80	0–10	I	96	1	100	1	—	—	—	—	—	—	
81–100	41–60	21–30	CD	—	—	—	—	94	2	97	1	—	—	

	No.	%
Increasing mortality with increasing stand density (*)........	6	33
Decreasing mortality with increasing stand density (**)......	7	39
No trend..	5	28
	—	
Total observations..	18	

(2) Mixedwood-softwood Types (SH)

In these types the degree of fir mortality was inversely related to the total stand density at the lower basal area values of fir, but was positively related to stand density when fir quantities exceeded 40 sq. ft. per acre (Table 41). In successively broader analyses (right-hand portion of Table 21, and Fig. 19) there was no evidence of a relation between mortality of fir and basal area of the whole stand.

On the whole there is not much evidence in SH types of a relation between fir mortality and the total basal area of the stand, although the trend in Table 41 cannot be ignored in view of the control of associated variables.

TABLE 40

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of the Whole Stand, with Control of Basal Area of Fir and of White Spruce

Broad Cover Type: Softwood

B.A. Fb	B.A. Sw	Basal Area of Whole Stand														Trend
		0–50		51–100		101–150		151–200		201–250		251–300		301+		
		Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–10	94	1	20	2	0	3	42	3	56	1	0	1	—	—	
0–20	11–20	0	1	2	2	—	—	—	—	—	—	—	—	—	—	
0–20	21–30	74	1	81	1	—	—	—	—	0	1	—	—	—	—	
0–20	41+	—	—	0	1	99	2	—	—	—	—	—	—	—	—	*
21–40	0–10	—	—	74	4	91	1	78	5	83	3	58	3	—	—	
21–40	11–20	94	1	—	—	—	—	84	1	—	—	50	1	—	—	**
21–40	21–30	—	—	86	3	95	2	—	—	—	—	—	—	—	—	*
41–60	0–10	—	—	85	5	80	7	65	6	76	5	—	—	62	2	**
41–60	11–20	—	—	100	1	34	1	84	2	—	—	—	—	—	—	
41–60	21–30	—	—	45	1	98	3	89	1	—	—	—	—	—	—	
41–60	31–40	—	—	—	—	98	3	87	2	—	—	—	—	—	—	**
61–80	0–10	—	—	98	2	86	5	87	5	26	1	—	—	—	—	**
61–80	11–20	—	—	74	1	87	2	94	2	—	—	84	1	—	—	
61–80	21–30	—	—	—	—	68	1	—	—	98	1	97	1	—	—	*
61–80	41+	—	—	—	—	82	5	98	2	—	—	—	—	—	—	*
81–100	0–10	—	—	—	—	88	5	98	1	—	—	—	—	—	—	*
81–100	11–20	—	—	—	—	93	1	70	1	98	1	—	—	—	—	
81–100	21–30	—	—	—	—	—	—	95	3	97	1	—	—	—	—	
101+	0–10	—	—	—	—	97	4	98	2	—	—	—	—	—	—	

	No.	%
Increasing mortality with increasing stand density (*)........	5	26
Decreasing mortality with increasing stand density (**)......	4	21
No trend..	10	53
Total observations..	19	

TABLE 41

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of the Whole Stand, with Control of Basal Area, Percentage and Relative Height of Fir, and Basal Area of White Spruce

Broad Cover Type: Mixedwood-softwood (SH)

Variables Controlled within Indicated Limits				Basal Area of Whole Stand										Trend
				0–50		51–100		101–150		151–200		201–250		
B.A. Fb	% Fb	B.A. Sw	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	0–10	CD	—	—	75	1	—	—	61	1	—	—	**
21–40	21–40	0–10	CD	—	—	97	1	82	2	—	—	—	—	**
21–40	21–40	0–10	I	—	—	93	1	76	1	—	—	—	—	**
21–40	21–40	11–20	I	—	—	80	1	63	3	—	—	—	—	**
41–60	21–40	0–10	I	—	—	—	—	36	1	66	2	56	1	*
41–60	21–40	11–20	CD	—	—	—	—	79	1	92	1	—	—	*
41–60	21–40	21–30	CD	—	—	—	—	92	1	97	1	—	—	*
41–60	41–60	0–10	CD	—	—	79	3	95	1	—	—	—	—	*
81–100	41–60	0–10	CD	—	—	—	—	88	1	85	3	—	—	
81–100	41–60	0–10	I	—	—	—	—	—	—	62	1	82	1	*

	No.	%
Increasing mortality with increasing stand density (*)........	5	50
Decreasing mortality with increasing stand density (**)......	4	40
No trend..	1	10
Total observations..	10	

TABLE 42

Percentage Mortality of Balsam Fir in Plots Segregated on the Basis of Basal Area of the Whole Stand, with Control of Basal Area, Percentage and Relative Height of Fir, and Basal Area of White Spruce

Broad Cover Type: Mixedwood-hardwood (HS)

Variables Controlled within Indicated Limits				Basal Area of Whole Stand								Trend
				0–50		51–100		101–150		151–200		
B.A. Fb	% Fb	B.A. Sw	Ht. Fb	Mort.	n	Mort.	n	Mort.	n	Mort.	n	
0–20	0–20	0–10	CD	—	—	—	—	63	1	81	1	*
0–20	0–20	0–10	I	—	—	91	1	67	2	—	—	**
0–20	0–20	0–10	U	—	—	0	1	0	1	—	—	
0–20	0–20	11–20	U	—	—	68	1	71	1	—	—	
0–20	0–20	31–40	CD	—	—	0	1	70	1	—	—	*
0–20	21–40	0–10	I	51	1	99	1	—	—	—	—	*
21–40	0–20	0–10	I	—	—	—	—	48	2	68	1	*
21–40	0–20	11–20	I	—	—	—	—	42	1	66	1	*
21–40	0–20	21–30	I	—	—	—	—	50	1	42	2	**
21–40	21–40	0–10	CD	—	—	81	3	65	3	—	—	**
21–40	21–40	0–10	I	—	—	—	—	44	3	59	2	*
21–40	21–40	11–20	CD	—	—	73	1	78	2	69	1	
41–60	0–20	0–10	I	—	—	—	—	69	1	79	3	*
41–60	0–20	0–10	CD	—	—	—	—	62	1	76	3	*

	No.	%
Increasing mortality with increasing stand density (*)........	8	57
Decreasing mortality with increasing stand density (**)......	3	21
No trend..	3	21
Total observations..	14	

TABLE 43

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area of the Whole Stand, with Control of Relative Height and Percentage of Fir

Broad Cover Type: Mixedwood-hardwood (HS)

Rel. Ht. Fb	% Fb	Basal Area of Whole Stand																	
		0–50			51–100			101–150			151–200			201–250			251–300		
		Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n	Fb	Sw	n
CD	0–20	—	—	—	0	44	1	69	38	5	78	97	2	—	—	—	—	—	—
	21–40	—	—	—	76	47	5	68	17	8	75	35	4	—	—	—	—	—	—
	41–60	—	—	—	—	—	—	97	0	1	—	—	—	—	—	—	—	—	—
	Average	—	—	—	75	46	6	71	26	14	75	57	6	—	—	—	—	—	—
I	0–20	—	—	—	91	0	1	47	23	9	49	40	5	—	—	—	—	—	—
	21–40	51	0	1	99	0	1	44	47	6	72	43	9	—	—	—	42	0	1
	41–60	—	—	—	—	—	—	84	0	1	—	—	—	—	—	—	—	—	—
	Average	51	0	1	95	0	2	47	31	16	66	41	14	—	—	—	42	0	1
U	0–20	—	—	—	55	0	3	50	25	3	41	32	3	—	—	—	—	—	—
	21–40	—	—	—	—	—	—	61	32	4	—	—	—	90	0	1	—	—	—
	Average	—	—	—	55	0	3	58	28	7	41	32	3	90	0	1	—	—	—
Total Average		51	0	1	76	38	11	60	29	37	66	42	23	90	0	1	42	0	1

(3) Mixedwood-hardwood Types (HS)

Increasing fir mortality appeared to be fairly consistently associated with an increase in total stand density (Table 42). This may have resulted from the vigour of balsam fir decreasing with increasing shade and increasing competition. When unimportant variables (Table 43), and all associated variables (Fig. 20) were uncontrolled, there was no evidence of fir mortality being affected by stand density. In the mixedwood-hardwood types, increased pooling of the data appeared to destroy the trend between percentage mortality of fir and total stand density. However, on the basis of the results in Table 42, there was some evidence that in this broad cover type, fir mortality increased with stand density.

The foregoing conclusions were based on a selected group of localities where the over-all fir mortality in each was quite high and fairly uniform. It was thought that the importance of the variables should be tested further by considering the data for broad cover types in specific watersheds. If any variable found to be important thus far, should prove unimportant in a broad cover type in any individual area, then that variable should be dropped in the analysis of detailed cover type within the area.

Only the Mississagi and Montreal River areas were suitable for testing. The same general procedure of analysis was followed as in the previous section, and the results are given in Table 44, where they are also compared with a summary of the above results.

TABLE 44

Tabulation of the Importance on Fir Mortality in the Mississagi and Montreal River areas, of Those Variables found to be Important in the Areas of Moderately High Over-all Mortality

Localities	Type of Analysis	Variables under Study														
		Basal Area of Fir			Percentage of Fir			Relative Height of Fir			Basal Area of Sw			Basal Area of Stand		
		S	SH	HS	S	SH	HS	S	SH	HS	S	SH	HS	S	SH	HS
Michipicoten R.; Manitowik L.; Montreal R. (eastern); Ranger L. (northeastern)		**	†	0[1]	?	0	†	*	*	†	†	0	0	0	†	†
Mississagi River	(a) Detailed tabular	*	?	—	—	—	†	†	0	†	0	—	—	—	0	0
	(b) Groups broadened	**	*	—	—	—	0	*	?	**	0	—	—	—	†	0
	(c) No variables controlled	**	*	—	—	—	0	*	0	†	0	—	—	—	0	0
Montreal River	(a) Detailed tabular	†	0	—	—	—	*	0	†	†	†	—	—	—	0	0
	(b) Groups broadened	**	**	—	—	—	**	0	0	**	*	—	—	—	*	**
	(c) No variables controlled	**	0	—	—	—	†	0	0	†	*	—	—	—	0	0

0 .... no evidence of influence on fir mortality
† .... some evidence of influence on fir mortality
* .... good evidence of influence on fir mortality
** .... very good evidence of influence on fir mortality

[1] Variables found to be of no importance in the Michipicoten-Manitowik area, were not investigated in the Mississagi and Montreal R areas.

In general, the detailed breakdown "a", where the variables were controlled within relatively narrow limits, fragmented the data too much. The type "b" analysis was probably the most adequate for the two individual areas, and therefore its results were taken as the main guide to the importance of each variable. Tables 61 to 63 for the Mississagi area, and Tables 64 to 66 for the Montreal River area (Appendix C) present the actual mortality figures in the type "b" analysis, showing the direction of each trend.

With reference to the Mississagi, and to softwood types in particular, this study demonstrates the difficulty of assessing the importance of variables where the average level of fir mortality in most types was over 90 per cent.

The general results portrayed in Table 44 indicate that the effect of each variable on fir mortality varied with locality, possibly indicating variability with the general intensity of infestation, or the preponderance of particular tree species. Basal area per acre of balsam fir was the most important variable and in general, appeared fundamentally important in regulating the degree of balsam-fir mortality within areas of heavy damage in Algoma. Also, there was fairly consistent evidence of a relation of fir mortality to relative height of fir.

EFFECT OF TREE COVER TYPE ON MORTALITY OF FIR

Cover type, as used here, includes associations of tree species, and the relative proportion of hardwood in stands. In analysis of the influence of associations of tree species, the following comparisons of fir mortality were made: firstly, within softwood and mixedwood stands in which the softwood content was predominantly fir-spruce, pine, cedar, or mixtures of these species; and secondly, within mixedwood and hardwood stands in which the hardwood content was predominantly intolerant or tolerant species.

The first comparison was within each broad cover type, followed by comparisons among the broad types. Only in the group of softwood types (Table 45)

TABLE 45

Percentage Mortality of Balsam Fir by Detailed Cover Types Within the Softwood Group, Controlling Within Broad Limits Those Variables Shown to Affect Fir Mortality in Softwood Types

Controlled Variables			Detailed Cover Types																Types Grouped by Characteristic Species							
B.A. Fb	B.A. Sw	Ht. Fb	S_1FS		S_1P		S_1C		S_1M		S_2FS		S_2P		S_2C		S_2M		SFS		SP		SC		SM	
			Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n	Fb	n
0-40	0-20	U	37	1	0	6	—	—	—	—	23	2	48	4	—	—	—	—	17	3	29	10	—	—	—	—
		I	87	6	76	6	84	2	58	1	74	1	62	4	—	—	—	—	82	7	70	10	84	2	58	1
		CD	92	1	—	—	—	—	—	—	—	—	—	—	62	1	74	2	92	1	—	—	62	1	74	2
	21+	U	90	1	—	—	—	—	—	—	94	2	0	1	—	—	—	—	93	3	0	1	—	—	—	—
		I	85	3	99	1	—	—	—	—	89	6	—	—	—	—	—	—	88	9	99	1	—	—	—	—
		CD	—	—	—	—	100	1	—	—	0	1	—	—	—	—	—	—	0	1	—	—	100	1	—	—
41+	0-20	U	—	—	—	—	—	—	—	—	65	2	71	1	—	—	26	1	65	2	71	1	—	—	26	1
		I	87	14	74	7	100	1	—	—	82	10	83	2	60	1	87	1	90	24	76	9	82	2	87	1
		CD	91	13	—	—	100	1	—	—	91	11	—	—	58	1	97	1	91	24	—	—	79	2	97	1
	21+	U	—	—	98	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98	1	—	—	—	—
		I	99	9	97	1	—	—	—	—	83	5	—	—	—	—	—	—	93	14	97	1	—	—	—	—
		CD	92	8	—	—	—	—	—	—	90	6	—	—	70	1	—	—	91	14	—	—	70	1	—	—

were there sufficient samples to permit a comparison of detailed cover types when all important variables were controlled, and even here a firm interpretation of results was hampered by fragmentary data. Within each of the S_1 and S_2 series of detailed types in the left-hand portion of Table 45, it is unsatisfactory to make comparisons of fir mortality among types because many of the calculations are based on only one plot, and numerous gaps occur in the data.

Plots were grouped by suppression of the differences between S_1 and S_2 subdivisions of softwood types, but by maintenance of distinctions based on characteristic species (right-hand portion of Table 45). Even here consistent trends were not evident. The data in Table 45 strongly point to the need for pooling plots by the submergence of one or more of the controlled variables.

Since the quantity per acre and relative height of fir were the variables which most consistently affected fir mortality among the broad types, only these variables are controlled in subsequent analyses of the influence of cover type.

TABLE 46

Percentage Mortality of Balsam Fir and White Spruce in Cover Types Grouped by the Predominant Softwood Component, with Control of Basal Area and Relative Height of Fir for Both the Softwood and Mixedwood General Types

Subdivisions of Softwood Types (S)

B.A. Fb	Ht. Fb	SFS				SP				SC				SM			
		Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	U	56	13	21	6	28	13	8	11	—	—	—	—	—	—	—	—
	I	85	47	30	16	71	42	32	11	84	50	19	2	58	70	16	1
	CD	84	0	16	2	—	—	—	—	71	0	34	2	74	47	30	2
	Average	80	33	26	24	62	27	20	22	74	1	29	4	68	60	23	3
41+	U	65	31	69	2	84	57	65	2	—	—	—	—	26	0	56	1
	I	88	48	67	38	78	24	57	10	82	0	50	2	87	0	54	1
	CD	91	54	78	38	—	—	—	—	72	6	47	3	97	0	60	1
	Average	89	51	72	78	80	37	60	12	77	4	48	5	65	0	56	3
Tot. Average		88	47	61	102	72	31	32	34	76	3	40	9	66	50	36	6
		(1)[1]				(3)				(2)				(4)			

Subdivisions of Mixedwood-softwood Types (SH)

B.A. Fb	Ht. Fb	SH_{FS}				SH_P				SH_C				SH_M			
		Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	U	86	21	17	4	—	—	—	—	—	—	—	—	44	26	27	1
	I	68	40	31	10	56	7	26	2	43	0	16	1	—	—	—	—
	CD	74	48	30	9	—	—	—	—	85	42	21	5	—	—	—	—
	Average	72	41	22	23	56	7	26	2	82	41	21	6	44	26	27	1
41+	U	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	I	79	41	58	19	76	—	49	2	—	—	—	—	56	0	45	1
	CD	85	29	61	27	—	—	—	—	55	82	42	3	—	—	—	—
	Average	82	34	60	46	76	—	49	2	55	82	42	3	56	0	45	1
Tot. Average		80	37	44	69	67	7	35	4	70	49	27	9	51	17	34	2
		(1)				(3)				(2)				(4)			

[1] The numerical sequence of each panel is according to the degree of fir mortality in the "total average" row.

A test for the effect of associations of tree species on fir mortality was made within the S and SH broad types (Table 46). When both basal area and relative height of fir were held under control, mortality of fir was usually highest in stands where the softwood component was mainly fir-spruce. Aside from this trend, there was no consistent sequence of fir mortality among the other groups. When the relative height of fir was submerged ("average" rows of Table 46), the mortality was again generally highest in the fir-spruce types. The one exception, where fir mortality was 82 per cent in the SH_C type and only 72 per cent in the SH_{FS} type, might be explained by the predominance of co-dominant fir in plots representing the former type, and the large proportion of intermediate fir in plots representing the latter type. As explained earlier, fir mortality tended to be greater in stands with co-dominant fir than in stands with only intermediate fir. Trends are more clearly shown in the "total average" rows, where all variables are submerged except cover type itself. Cedar and pine types had, on the whole, about the same degree of fir mortality, and followed the fir-spruce types. Fir appeared to suffer the least damage in types where the softwood content was mixed. The net result was that the fir-spruce type in both the S and SH series had the greatest mortality of fir, followed by cedar types, pine types, and finally types where the coniferous content was mixed. This sequence, based on the "total average" rows of Table 46, is indicated at the bottom of each cover-type panel. The HS type series was not sufficiently complete to allow comparisons.

To investigate the effect on fir mortality of the second aspect of species associations, namely, the presence of intolerant versus tolerant hardwoods, appropriate data are compared in Table 47. Although the variability within the body of the table leads to inconclusive results, there was a tendency ("total average" row) for the mortality of fir to be less in those mixedwood stands characterized by tolerant hardwoods; and in hardwood stands, to be greater where tolerant hardwoods predominated.

In Fig. 11, the wide range of fir mortality in the HSI_{FS} type appeared unusual, in view of the high degree of fir mortality over the Mississagi River area, and prompted an attempt to discover possible factors associated with the plots having low fir mortality. An examination of the variables under study did not reveal any explanation for the large number of plots with low mortality. However, those stands in which the hardwood overstory was predominantly aspen seemed to have higher balsam-fir mortality than those with a predominantly white-birch overstory. Appropriate sample plots in the HSI_{FS} type were studied to bring out the possible effect of aspen and of white-birch overstory on balsam-fir mortality. The sample plots were divided into two groups; those in which the hardwood content was over 50 per cent aspen, and those in which the hardwood was over 50 per cent white birch. Borderline examples were avoided. Balsam-fir mortality averaged 51 per cent in stands overtopped by white birch, and 85 per cent in stands overtopped by aspen. A possible explanation lies in the type of crown of each species. Aspen crowns are inclined to be thin, allowing more light to reach the understory than in the case of white birch. This increased light would aid budworm development. Also, defoliation by the forest tent caterpillar, *Malacosoma disstria* Hbn., in the early 1930's may have caused serious injury to aspen crowns, thus reducing their protective value. The observation that fir mortality was greater under aspen than under birch did not appear to be a generality, since it did not hold true in the other areas. However, forest conditions exemplified by the Mississagi stands were not fully duplicated by stands in the other localities.

An indication that the proportion of hardwood affected fir mortality is shown in Fig. 10 where plots of three cover types representing variations in percentage of hardwood, are grouped by topographic sites. The mortality of fir decreased from the SFS type to the HSI_{FS} type under each topographic

TABLE 47

Comparison of Percentage Mortality of Balsam Fir between Plots Segregated According to Hardwood Tolerance

Controlled Variables		Detailed Cover Types																							
		SHI_{FS}		SHT_{FS}		SHI_C		SHT_C		HSI_{FS}		HST_{FS}		HSI_C		HST_C		H_1I		H_1T		H_2I		H_2T	
B.A. Fb	Rel. Ht. Fb	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n	Mort. Fb	n
0–40	U	86	4	—	—	—	—	—	—	55	12	—	—	—	—	—	—	17	5	—	—	24	5	39	1
	I	68	10	—	—	—	—	43	1	46	21	61	2	0	1	—	—	4	3	57	2	—	—	—	—
	CD	73	6	78	3	91	3	81	2	73	17	60	2	—	—	81	1	57	4	90	1	—	—	80	1
	Average	72	20	78	3	91	3	75	3	58	50	61	4	0	1	81	1	42	12	68	3	24	5	67	2
41+	U	—	—	—	—	—	—	—	—	90	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	I	79	19	—	—	—	—	—	—	72	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	CD	85	27	—	—	58	2	53	1	73	5	61	1	—	—	—	—	—	—	—	—	—	—	—	—
	Average	82	46	—	—	58	2	53	1	73	16	61	1	—	—	—	—	—	—	—	—	—	—	—	—
Total Average		80	66	78	3	75	5	66	4	64	66	61	5	0	1	81	1	42	12	68	3	24	5	67	2

condition. Also, in the exploratory analysis for the effect of basal area of fir on fir mortality (Figs. 11 and 12), the degree of scattering of the points in the graphs increased as the percentage of hardwood increased. This probably indicates a modifying effect of increased hardwood on fir mortality.

The effect of percentage hardwood in stands may be more adequately determined by comparing detailed types, having the same general softwood component, when important variables are controlled. In the left-hand portion of Table 45, comparisons of identical types, differing only in the percentage of hardwood content (S_2 representing 76-87 per cent softwood, S_1 representing over 87 per cent softwood), reveal a slight tendency for balsam-fir mortality to be higher in the types with higher total softwood content. For example, with basal area of fir at 0 to 40 sq. ft., basal area of white spruce at 0 to 20 sq. ft., and relative height of fir classed as "I", fir mortality in type S_1P was 76 per cent, and in type S_2P, 62 per cent. However, several discrepancies occur and there are numerous gaps in the data, so that firm conclusions regarding the influence of hardwood content within narrow types, cannot be drawn from the data in the left-hand portion of Table 45. By dropping basal area of white spruce as a variable and extending the comparison to include mixedwood types, a clearer trend emerged to illustrate the effect of hardwood (Table 48). In this

TABLE 48

Relation of Percentage Mortality of Fir and White Spruce to Percentage Hardwood in Stands, by comparing Detailed Cover Types Wherein the Softwood Component Species and the Variables found to Affect Fir Mortality are Controlled Within Broad Limits

Controlled Variables		S_1FS					S_2FS					SHI_{FS}					HSI_{FS}				
B.A. Fb	Ht. Fb	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n
0–40	I	87	52	25	10	9	84	45	34	25	7	68	40	31	16	10	46	36	25	16	21
41+	I	93	55	71	20	23	82	40	63	15	15	79	41	58	12	19	72	41	55	9	10
41+	CD	92	61	78	22	21	91	44	77	18	17	85	29	61	12	27	73	13	49	8	5
		S_1P					S_2P					SHI_P					—				
0–40	I	77	58	33	8	7	62	0	31	4	4	56	7	26	12	2	—				

table, four sequences of detailed types, with sufficient samples in each to be meaningful, are presented for special attention. The type designations represent stands with similar softwood species, but which differ in that the proportion of intolerant hardwoods increases from S_1 types through to the HS types. By definition (Table 3), the range of hardwood content in stands designated as either S_1FS or S_2FS is a maximum of 12 per cent (e.g. S_1FS types may contain from 88 per cent to 100 per cent softwood). On the other hand, the range of hardwood content in stands designated as either SHI_{FS} or HSI_{FS} is a maximum of 25 per cent (e.g. the SHI_{FS} type may contain 51 per cent to 75 per cent softwood, and consequently, 25 per cent to 49 per cent hardwood). Therefore, to equalize the range of hardwood content, plots of the S_1FS type should strictly be combined with those of the S_2FS type. However, any difference in fir mortality between S_1FS and S_2FS, or between S_1P and S_2P, within rows of Table 48 where comparable quantities of fir are involved, illustrates the influence of a rather small change in hardwood content, and thus adds further refinement to the analysis. Comparable figures of fir mortality with increasing hardwood content in Table 48 are as follows:

1st row.................................... 87,84,68,46
2nd row.................................... 93,82,79,72
3rd row.................................... 92,91,85,73
4th row.................................... 77,62,56,—

In all cases there was a distinct decrease in fir mortality with increasing proportions of hardwood. The effect on white-spruce mortality was similar.

The study of hardwood content was extended to the broad cover types. Table 49 summarizes mortality, in progressively larger groupings of the data from the top to the bottom of the table. Here again there is general evidence

TABLE 49

Percentage Mortality of Balsam Fir and White Spruce by Broad Cover Types, Controlling Within Broad Limits those Variables Shown to Affect Fir Mortality in all Broad Cover Types

B.A. Fb	Ht. Fb	S_1				S_2				SH				HS				H_1				H_2			
		Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0-40	U	21	12	8	8	55	14	16	9	67	21	20	5	55	28	24	13	—				—			
	I	80	57	27	19	77	41	33	11	65	33	30	13	47	34	25	24	—				—			
(1)	CD	95	0	31	2	68	15	32	4	75	46	28	14	73	41	27	20	—				—			
41+	U	98	70	71	1	60	18	63	4	—	—	—	—	90	0	59	1	—				—			
	I	90	50	67	32	82	39	61	19	78	40	57	22	72	41	55	10	—				—			
(1)	CD	92	61	77	22	90	40	74	20	84	32	60	30	73	13	49	6	—				—			
0-40	Tot.	74	41	21	29	71	28	27	24	71	39	28	32	59	35	25	57	46	35	12	15	54	31	5	7
41+	Tot.	91	56	72	55	83	39	71	43	82	35	59	52	73	29	52	17	—				—			
(2)																									
All variables combined (3)		89	53	54	84	81	35	53	67	79	37	46	84	64	34	31	74	46	35	12	15	54	31	5	7
		S								SH				HS				H							
All variables combined (4)		85	44	53	151					79	37	46	84	64	34	31	74	47	34	10	22				

DESCRIPTION OF TREATMENT OF PLOT DATA

(1) Data segregated by broad types, S_1, S_2, etc., and by basal area and relative height classes of fir.
(2) Data segregated by broad types and by basal area of fir per acre (relative height classes of fir submerged).
(3) Data segregated by broad types only (basal area and relative height classes of fir combined).
(4) Data segregated by broader types, i.e. combining of S_1 and S_2, and H_1 and H_2, thus creating four broad type categories which differ successively, from softwood to hardwood, by 25% intervals of increasing hardwood content.

that fir mortality decreased with increased percentage of hardwood. However, where fir concentrations were over 40 sq. ft. per acre, there is an indication that the control of fir basal area is not adequate, since the range in fir content among the broad types is such that decreasing mortality could result from decreasing quantities of fir as well as from increasing quantities of hardwood.

This difficulty was overcome (Table 50) by grouping plots within narrower ranges of fir content. On the whole, there is still evidence that fir mortality decreased with increased percentage of hardwood, especially between S and HS types. The difference between S and SH types was not marked. Where the balsam fir was intermediate, fir mortality fairly consistently decreased with increased percentage of hardwood. Where fir was co-dominant, the proportion of hardwood did not seem to have a marked effect on fir mortality. Where fir was understory, the effect of hardwood content was not consistent, although at lowest concentrations of fir the mortality increased with increased hardwood.

With the data grouped into broad cover types (S, SH, HS), and with only basal area and relative height of fir controlled, there were sufficient samples to warrant a test of the effect of hardwood content by means of regression lines. Regressions of fir mortality on basal area of fir, by relative height-classes of fir

TABLE 50

Percentage Mortality of Balsam Fir and White Spruce by Broad Cover Types, with Control of Basal Area and Relative Height of Fir

Basal Area Fb	Rel. Ht. Fb	S Mort. Fb	S Mort. Sw	S n	SH Mort. Fb	SH Mort. Sw	SH n	HS Mort. Fb	HS Mort. Sw	HS n
0–20	CD	0	—	1	77	65	7	66	39	7
	I	76	36	6	30	7	4	62	13	8
	U	12	8	13	53	22	2	62	23	6
	Average	35	16	20	58	46	13	63	25	21
21–40	CD	76	19	5	76	32	8	74	42	13
	I	80	47	23	71	42	9	46	42	16
	U	71	21	4	60	20	2	54	34	7
	Average	78	39	32	74	33	19	58	41	36
41–60	CD	88	57	15	84	29	14	73	13	6
	I	80	47	24	77	32	13	71	38	6
	U	52	95	3	—	—	—	90	0	1
	Average	80	52	42	80	30	27	73	24	13
61–80	CD	90	80	10	91	18	6	—	—	—
	I	85	39	19	85	54	7	73	44	4
	U	85	68	2	—	—	—	—	—	—
	Average	87	56	31	88	34	13	73	44	4
81–100	CD	87	27	9	75	75	9	—	—	—
	I	99	76	5	69	71	2	—	—	—
	U	—	—	—	—	—	—	—	—	—
	Average	92	40	14	74	75	11	—	—	—
101+	CD	97	21	7	—	—	—	—	—	—
	I	99	47	3	100	0	1	—	—	—
	U	—	—	—	—	—	—	—	—	—
	Average	98	27	10	100	0	1	—	—	—

and broad cover types, are presented in Fig. 22. Only the three regressions pertaining to S types showed significant slopes. However, the following synopsis, which gives percentage fir mortality for selected quantities of fir per acre drawn from Fig. 22, is of interest.

Broad Cover Type	U B. A. Fb 20	U 30	U 40	I B. A. Fb 30	I 40	I 50	I 60	CD B. A. Fb 30	CD 40	CD 50	CD 60	CD 70	CD 80
S	31	40	50	74	78	80	83	72	76	79	82	85	89
SH	63	72	80	62	66	70	74	77	79	80	81	82	83
HS	44	56	67	56	60	64	68	69	74	79	83	—	—

Considering only the effect of hardwood on fir mortality (i.e. reading vertically) this summary corroborates in general the findings drawn from Table 50, viz., that increasing proportions of hardwood decreased fir mortality when

the fir was intermediate in height. Where the firs were co-dominant, changes in proportions of hardwood were apparently unrelated to fir mortality. This finding is in accord with that of Craighead (8). Where fir was understory, the mortality in the HS types was greater than in the S types (samples for SH types were entirely inadequate), suggesting that increased shading was detrimental. The latter observation differs from that reached by Craighead (7, 8),

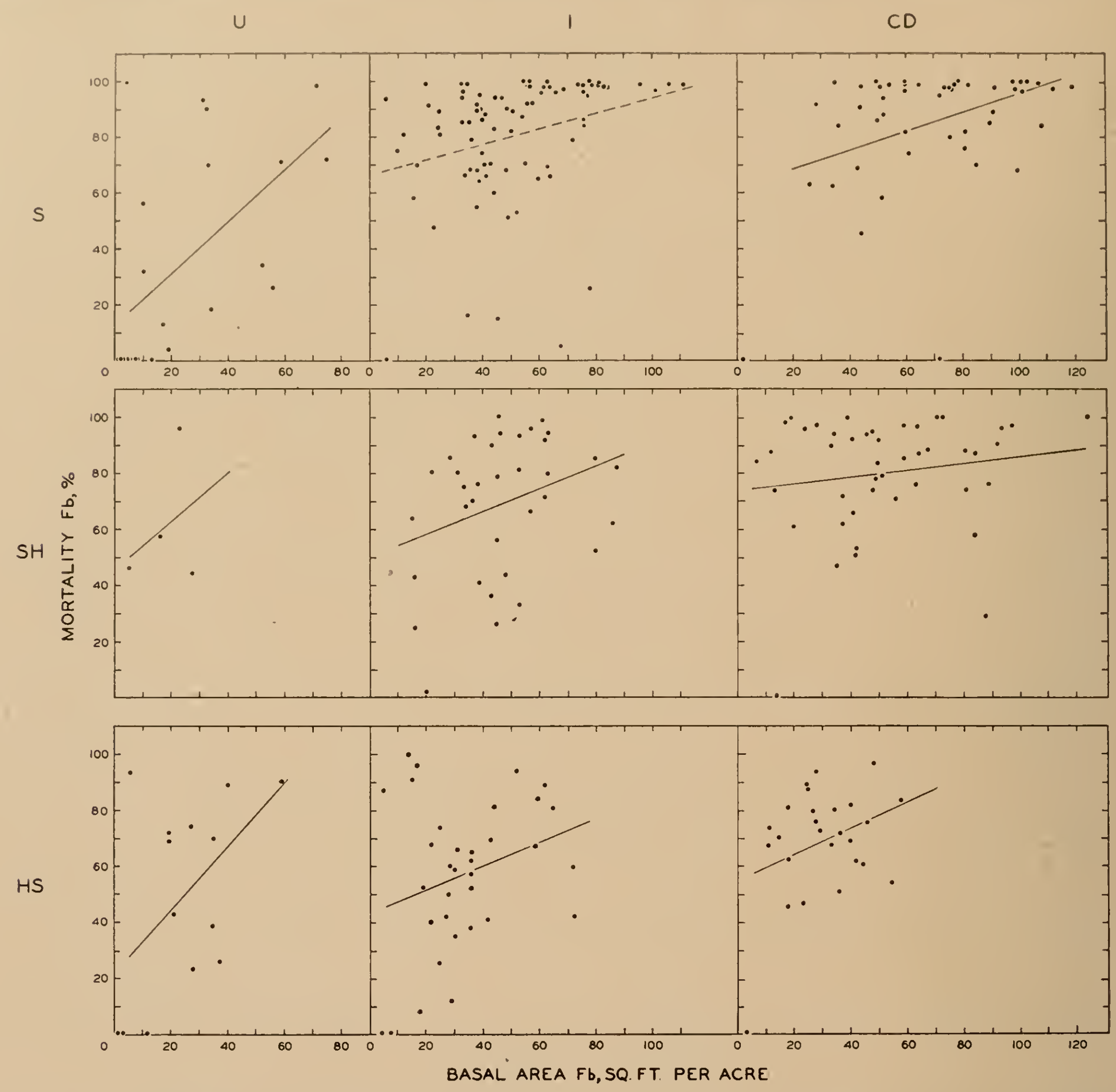

Fig. 22.—Regressions of percentage mortality of fir on basal area of fir per acre in plots segregated by relative height classes of fir and broad cover type. Only the upper three lines (those pertaining to S types) have significant slopes. The regression line for plots in softwood types and containing intermediate fir is broken, because a curved line would more properly fit the distribution of points. However, a curved line would merely improve somewhat a relation which is already quite consistent (see synoptic table in text).

who found that hardwoods were a protection to softwoods only while the softwoods were completely overtopped; but is in agreement with that reached by Swaine (30) who noted, in the eastern Ontario outbreak of 1920, that severe fir mortality occurred in stands where the fir was overtopped by hardwoods. Investigating southern pines, Beal (4) also found that shaded trees succumbed to defoliation more easily; open-grown trees survived up to 76 per cent defoliation, whereas shaded trees often died with 50 per cent defoliation. One would therefore conclude that firs overtopped by hardwoods are more seriously weakened by shading, than those overtopped by softwoods, and are therefore more liable to mortality when attacked. This may explain the higher mortality of fir in tolerant hardwood types where shade is intense, than in intolerant hardwood types (Table 47).

The foregoing analysis of the influence of cover type was extended to each of the Mississagi River and Montreal River areas, to test the more general applicability of the conclusions just reached. Tables 67-69 for the Mississagi area and Tables 70-72 for the Montreal River area (in Appendix D) present the more important statistics by cover type. In the following synopsis the results are compared and show the sequence of fir mortality (1—highest; . . .4—lowest) in the main species associations. The "net sequence" is based on percentage of fir mortality, calculated by adding the quantities of fir actually tallied in all three localities under analysis.

Broad Cover Type	Source of Data		Softwood Component of Stand			
	Locality	Table	Fir-Spruce	Pines	Cedar	Mixed
S	Michipicoten R.—Manitowik L. etc.	46	1	3	2	4
	Mississagi R.	67	1	2	4	3
	Montreal R.	70	1	2	4	3
		Net sequence	1	2	4	3
SH	Michipicoten R.—Manitowik L. etc.	46	1	3	2	4
	Mississagi R.	67	2	4	1	3
	Montreal R.	70	3	1	4	2
		Net sequence	1	2	4	3
HS	Mississagi R.	67	2	1	3	4
	Montreal R.	70	1	3	2	—
		Net sequence	1	2	3	4

Within the SH and HS cover types especially, the effect of species associations on the sequence of fir mortality showed some variability between the Mississagi and Montreal River areas, and was somewhat at variance with the results of the areas treated in Table 46. Two noticeable features of Tables 67 and 70 are the high fir mortality in pine softwood types and the relatively low fir mortality in cedar softwood types. This may be a direct reflection of site conditions rather than the influence of the trees themselves. The "net sequence" in all three broad types is also at variance with the results of Table 46, chiefly because the fir mortality in pine types is influenced by a preponderance of samples from the Mississagi River area where the fir mortality in pine types was very high, and because the mortality in cedar types is influenced by a preponderance of samples from the Montreal River area where the fir mortality in cedar types was relatively low.

Apart from highest fir mortality usually occurring in stands where the softwood component was mostly fir-spruce, the above synopsis shows that the relative degree of fir mortality in the various cover types may be expected to vary with locality. Although the results of the Michipicoten-Manitowik areas (Table 46) are possibly the most reliable, they apparently did not hold true very widely, since there is a noticeable lack of agreement with the Mississagi and Montreal River areas. If the "net sequence" row is accepted as representing an average condition for most of the heavily damaged sections of Algoma, the highest degree of fir mortality occurred in types where the softwood component was characterized by fir-spruce or pine, and was lower where this component was chiefly cedar or a mixture of species. However, even the least-damaged types had severe fir mortality.

Tables 68, 69, 71 and 72 confirm the previous observation that, in general, a decrease in percentage of fir mortality accompanied an increase in percentage of hardwood in stands. However, as pointed out in the previous section, the effect of hardwood on fir mortality can only be properly assessed in relation to the relative height of fir. In each of the Mississagi and Montreal River areas, the number of sample plots containing the "U" and "CD" height categories of fir, were insufficient for critical assessment of the effect of hardwood.

Summing up the study of the influence of forest composition, the important factors affecting the degree of fir mortality were the basal area of fir per acre, the relative height of fir, the occurrence of fir-spruce cover types, and the proportion of hardwood in the forest. Percentage mortality of fir increased with basal area per acre and relative height of fir, was higher in stands where the softwood content was mainly balsam fir and spruce, and in general decreased with increased proportions of hardwood except where fir was in the understory.

Some of the results of this study are in rather sharp contrast with those obtained by Richmond (28) on a similar investigation of the jackpine budworm, *Choristoneura* sp., in stands containing jack pine. He found that species mixture, percentage of jack pine, and diameter size did not influence the degree of mortality.

The quantity of fir per acre has usually been considered by other investigators to be the most important single factor determining the budworm hazard of an area, and the degree of damage to fir once an outbreak is established. One of the important results of the present study is the conclusion that the average density of fir and white spruce over an area required to create a serious budworm hazard, with very high resultant mortality, is considerably lower than is generally thought (3, 36).

DISCUSSION

The purpose of the investigation was to determine which of the forest characteristics studied were associated with high resultant tree mortality after a spruce budworm epidemic. If this were accomplished, hazard areas could be recognized in advance of outbreaks, enabling effective pre-salvage operations; and the continued occurrence of conditions presenting a hazard could be reduced through forest management. However, the variability in fir mortality among localities of comparable forest composition in Algoma, suggests that prediction of the degree of mortality in any stand or forest area may be of limited accuracy. This limited accuracy probably results because conditions governing susceptibility of the forest to attack by the budworm, differ from those influencing vulnerability of the forest to mortality after an infestation has started. Consideration of the former was not within the scope of the present investigation, but recent contributions indicate the importance of climate (34), and of the physiological condition of balsam fir (5), in the development of infestations.

Vulnerability of the forest after an infestation has built up, will be influenced by the intensity and duration of the infestation, and by attributes of the stands. However, these latter factors may also contribute substantially to the former. The role of size and location of the infested forest in maintaining an intensive outbreak is not well understood, but in small isolated infestations the budworm population suffers constant drain through dispersal. In such areas, the budworm population may be unable to maintain itself at tree-killing intensity. An explanation of the low vulnerability of the forest in the Sheppard Creek, Chippewa River and the southwestern portion of the Ranger Lake area may be found in the small relative size and isolation of these stands by surrounding hardwood types. The data included in the following synopsis clearly show that the relation between fir mortality and prevalence of the host trees was entirely different in

the three localities mentioned, from that in the other localities where studies were carried out. The Manitowik Lake area is included in the synopsis to illustrate one of the other areas where over-all fir mortality was moderately high. For each locality listed, the data represent the fir content and fir mortality for the forest as a whole, and for the fir-spruce softwood type in particular.

Locality	Whole Forest		SFS Type	
	B.A. Fb Per acre	% Mort. Fb	B.A. Fb Per acre	% Mort. Fb
Ranger Lake, Strips 1-30 (see also Fig. 2)............	39	17	63	17
Sheppard Creek....................................	45	19	58	21
Chippewa River....................................	50	26	61	25
Manitowik Lake....................................	29	70	50	86

The low mortality in the first three localities is not traceable to low fir content. Moreover, as pointed out earlier, budworm infestations persisted in these areas for at least two or three seasons before subsiding.

The three areas of low mortality are illustrations of what is here called a "zone of survival", where the forest was susceptible, infestations developed but failed to persist, and consequently little mortality occurred. Their location to the southwest of the persistent outbreak (opposed to the direction of prevailing winds), their relative isolation by surrounding stands of tolerant hardwoods, and their closeness to Lake Superior which provided absolute isolation from that direction, were undoubtedly of immediate importance in ultimate survival of these stands. Zones of survival in other regions subjected to outbreaks are frequently noted in the peripheral areas, which become infested several years after development of the outbreaks in the focal areas. This latter condition is different from that which existed in southwestern Algoma, where infestations in the zones of survival were more or less concurrent with that in the main body of the outbreak.

It is often suggested that one aim of silvicultural practice should be to produce budworm-resistant forests by favouring the development of those forest cover-types that are not vulnerable to serious budworm damage (7, 13, 14). However, from the results of the studies in Algoma, one might doubt that any extensive type containing fir would be non-vulnerable. In the areas of sustained attack, even the least damaged of the softwood and mixedwood types suffered at least 50 per cent and generally over 60 per cent mortality of fir. From their observations in the Minnesota outbreak, Graham and Orr (14) state that fir overtopped by aspen, birch or pine, or occurring in predominantly hardwood or pine forests, is seldom severely defoliated even during an outbreak in adjacent stands. Balsam-fir trees occurring under these conditions in most of the heavily infested areas of Algoma suffered not only severe defoliation, but also almost complete mortality in many stands (Fig. 23).

Owing to the excellent reproductive and competitive capacity of balsam fir, and increasing protection from fire, it is certain that the fir content in potential danger areas throughout northern Ontario will, in the normal course of events, once again reach vulnerable limits. The only reasonable minimum approach to the problem seems to lie in the increased utilization of fir, of which the least benefit would be to lessen timber losses when outbreaks do occur. Also, greater accessibility of the forest and flexibility of working plans will encourage prompter and more effective salvage.

However, as noted, this is a minimum approach to the spruce budworm problem and implies reconciliation with the recurrent need for salvage operations and acceptance of heavy losses. The ultimate objective, namely the prevention of destructive outbreaks, requires long-term planning of forest operations based on sound ecological principles. All tree species and forest types occurring in areas of commercial timber operations, and the susceptibility of these species and types to budworm and other hazards, should be taken into account, and cutting operations planned to take advantage of full productivity. Such cutting operations should be directed towards developing stands best suited to the site, thus increasing stand vigour and gradually lessening the hazards confronting the forest (39).

With increasing uses for hardwoods, it is conceivable that these species should be encouraged not only because of their intrinsic values but also because the maintenance of hardwood canopy will probably aid considerably in preventing the occurrence of outbreaks. On a short-term basis, Heimburger (19) advocated the development of pure hardwood belts to restrict budworm epidemics. Several factors may influence the choice of hardwood species to be encouraged. Throughout northern Ontario the main species are aspen and white birch. Craighead (7) observed that in the birch-aspen cover types, as aspen overstory favours faster growth and better development of conifers. This is probably because the crowns are less dense than the crowns of white birch. The same author also states that aspen seems to give as good protection as birch. However this is doubtful on the basis of observations in the Mississagi area. Also, aspen is the favoured food of the forest tent caterpillar, and the periodic outbreaks of this insect not only disrupt the growth of aspen, but may also materially aid in the build-up of budworm populations (34). Therefore from the ecological viewpoint it would appear that white birch would be a more desirable species to favour, assuming that the problem of birch "dieback" can be largely reduced by maintaining the trees in a state of vigour.

Several investigators (3, 7, 8, 13, 14, 15, 21, 22, 24, 35-38) have suggested steps in forest management to reduce budworm hazard. In general, these aim at keeping the balsam fir young and vigorous and preventing its accumulation over wide areas, by utilization on the shortest rotation and to the smallest diameter possible. Appendix E contains a brief summary of the specific recommendations. Such recommendations have no immediate application throughout much of northern Ontario where most of the commercial balsam fir has been destroyed in recent years. However, as the new forest develops, plans should be laid for long-term management, and many of the recommendations for reducing vulnerability of the forest to the spruce budworm will undoubtedly have a place in practical woods operations in Ontario. In Eastern Canada the size and continuity of the forest presents a formidable problem in appropriate forest management, and of necessity the first steps in reducing hazard must be simple and economically feasible.

The recent outbreaks of the spruce budworm in Ontario have killed fir and white spruce over very large areas, and have caused changes in current operating plans, although there is little available evidence that the outbreaks have interfered with immediate wood procurement. However, the importance of the current damage cannot be assessed on present conditions alone, and will only become evident with continued operations of the limits. If the damage makes continued operations over the next 30 or 40 years more difficult, or even impossible, then the full influence of the recent outbreaks is still to be felt.

Regeneration studies by several investigators in the northeastern United States, the Maritimes, Quebec and Ontario, have shown that balsam fir is particularly prevalent in the seedling crop, and will probably be the predominant species in many stands. In addition, the increasing economic importance of

this species will undoubtedly make the budworm problem of greater concern in the future, as mill capacity more closely approximates the productive capacity of the forest within economic reach. Therefore, since the spruce budworm is an ever-present menace to fir and white spruce, every feasible step should be taken to keep the forest in a less susceptible state, and thus reduce the danger of extensive tree mortality.

SUMMARY

1. Examination of the annual rings of several old spruce trees from various localities, suggested the possibility of a spruce budworm epidemic in the Algoma forest commencing about the years 1832 to 1835.

2. The intensity and duration of a spruce budworm epidemic in the 1930's-1940's was quite variable in various localities throughout Algoma, evidenced by direct observations when the budworm was active and by the resultant damage to balsam fir and white spruce. In the localities under investigation, fir mortality, calculated on the basis of basal area at breast height of all trees of the 1-inch class and over, varied from about 20 per cent in the Sheppard Creek valley, to about 90 per cent in the Mississagi River watershed, as an average including all cover types.

3. Concepts developed by Westveld and Balch to determine budworm hazard failed to describe conditions resulting from the Algoma outbreak. These concepts are based on principles which are basically sound, in that they relate vulnerability to quantities of fir, or fir plus spruce. However, in the regions to which the concepts were intended to apply, fir occurs in much higher concentrations than in Algoma, and therefore failure to express vulnerability in the latter area probably resulted from considering stands with relatively low fir content as presenting very little hazard. Such stands were highly vulnerable in Algoma.

4. The tree cover of the Algoma forests was typed by percentage species composition based on the basal area at breast height. It was found that basal area of fir and spruce gave a somewhat better expression of the amount of foliage (insect food material) than did the total stem volume.

5. The main portion of the analysis dealt with localities where the overall mortality of fir was about 75 per cent. With the available data, only qualitative results were obtained. Each of several variables recorded in the investigation was analysed for its effect on the degree of fir mortality. Basal area per acre and relative height of fir were found to be important quite generally, and are referred to below. The influence of total age of fir, topographic site, percentage of fir in stands, basal area of the whole stand and basal area of white spruce per acre varied with cover type and with locality, and their general applicability could not be demonstrated with the data at hand.

6. Within all localities of generally high fir mortality, and in most broad cover types under investigation, the percentage mortality of fir increased with the basal area of fir per acre.

7. The relative height of fir appeared to have a general influence on percentage mortality of fir, since increasing fir mortality fairly consistently accompanied increasing relative height of fir in all broad cover types.

8. With the important variables controlled within specific limits, data from certain localities were selected to determine the effect of tree cover-type on fir mortality. There was some variability in results among the localities tested, but in general the highest degree of fir mortality occurred in types where the softwood component was mainly fir-spruce or pine, and was lower where this component was chiefly cedar or a mixture of species.

9. The influence of percentage of hardwood in stands on the degree of fir mortality was variable, depending on the relative height of the fir. Where

the fir was in the intermediate height class, percentage mortality of fir decreased with increasing proportions of hardwoods. Where the fir was understory, fir mortality tended to increase with increased proportions of hardwood, possibly owing to the resistance of fir trees being lowered with increased shade. Where the fir was co-dominant, the proportion of hardwood did not affect fir mortality to any extent.

10. The studies showed that the quantity of fir required to support an outbreak may be quite low. In the Mississagi River area, the average merchantable volume of balsam fir was about four cords per acre and in the Manitowik area, only about three cords per acre, conservative deductions having been made for cull. Outbreaks might well occur in areas where the merchantable volume of fir is considerably below three or four cords per acre.

11. High vulnerability at comparatively low densities of fir in the Algoma area of Ontario, may introduce difficulty into the problem of reducing hazard of the forest to the spruce budworm through forest management.

ACKNOWLEDGMENTS

The writer is greatly indebted to several members of the Forest Insect Laboratory, Sault Ste. Marie, Ontario: Dr. M. L. Prebble, Officer-in-charge, for his guidance throughout the course of the investigation and in the preparation of this contribution; Dr. R. M. Belyea and Dr. W. R. Henson for reviewing the paper in manuscript form and making valuable suggestions and criticisms; and Mr. D. C. Anderson for the field photography.

Appreciation is also expressed to Dr. C. E. Atwood, Department of Zoology, University of Toronto, for several helpful suggestions.

The field work was largely financed by the Department of Lands and Forests, Ontario, and Mr. J. A. Brodie deserves special thanks for his whole-hearted co-operation in the prosecution of the work.

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Fig. 23.—Dead balsam fir and white spruce under a 70-year old stand of white birch (Mississagi River October, 1947).

Fig. 24.—Combined result of budworm damage and pine logging, which was typical of much of the upper Mississagi watershed. Pine logging in this locality started after mortality of fir commenced. For the original composition of most of these stands, see Table 54, Appendix B (October, 1947).

Fig. 25.—A small stand of balsam fir in which all firs were killed. Surviving trees are white spruce (Mississagi River, October, 1947).

Fig. 26.—Healthy fir trees 40 to 50 feet high and up to 110 years of age in a mixedwood stand. The annual rings showed only slight reduction in growth, although defoliation was severe at time of outbreak (in area of light damage, Ranger Lake, October, 1947).

Fig. 27.—Stand of mature fir, 40 to 50 feet high and 80 to 90 years of age, in area of moderate mortality of fir, Ranger Lake (October, 1947). The site was formerly dominated by white pine.

Fig 28.—Dead fir trees with living white and black spruce in area of generally high fir mortality, Ranger Lake (October, 1947).

Fig. 29.—Dense, healthy stand of fir, averaging 7 inches D.B.H. (Sheppard Creek, September, 1947). Bare patch at top of tree in right background is a result of terminal budworm feeding around 1940.

Fig. 30.—Balsam fir tree 17 inches D.B.H., 81 feet high, and 95 years old, illustrating the type of fir trees commonly encountered in the Chippewa River valley. The tree shown had noticeably reduced diameter growth near the base for the period 1942–45. (July, 1947).

Fig. 31.—Mature to over-mature fir stand (100 years old) containing 110 sq. ft. of fir per acre. Average mortality of fir in this stand was 1%. Budworm feeding caused a sharp reduction in diameter growth (Chippewa River, July, 1947).

Fig. 32.—Change in stand composition during a 40-year period. Previous stand had a fire origin, and was chiefly jack pine and white spruce, with some white birch, poplar, and understory fir. Logging about 1904 removed the jack pine and spruce, and released the fir. The recent spruce budworm epidemic killed all firs, and the site has been taken over by shrubs, chiefly raspberry, *Rubus daeus* L. (Michipicoten River, July, 1947).

Fig. 33.—A stand of balsam fir where the site was formerly occupied chiefly by jack pine. The jack pine and some white spruce were logged about 1904, as evidenced by release in white spruce. Residual jack pines were 155 years old. Fir content in this stand was 100 sq. ft. per acre, and mortality of fir was 96% (Michipicoten River, July, 1947).

Fig 34.—Segment of stand averaging 100 sq. ft. of fir per acre for a distance of 10 chains along the cruise strip. Mortality of fir over this distance was 97% (Manitowik Lake, August, 1947).

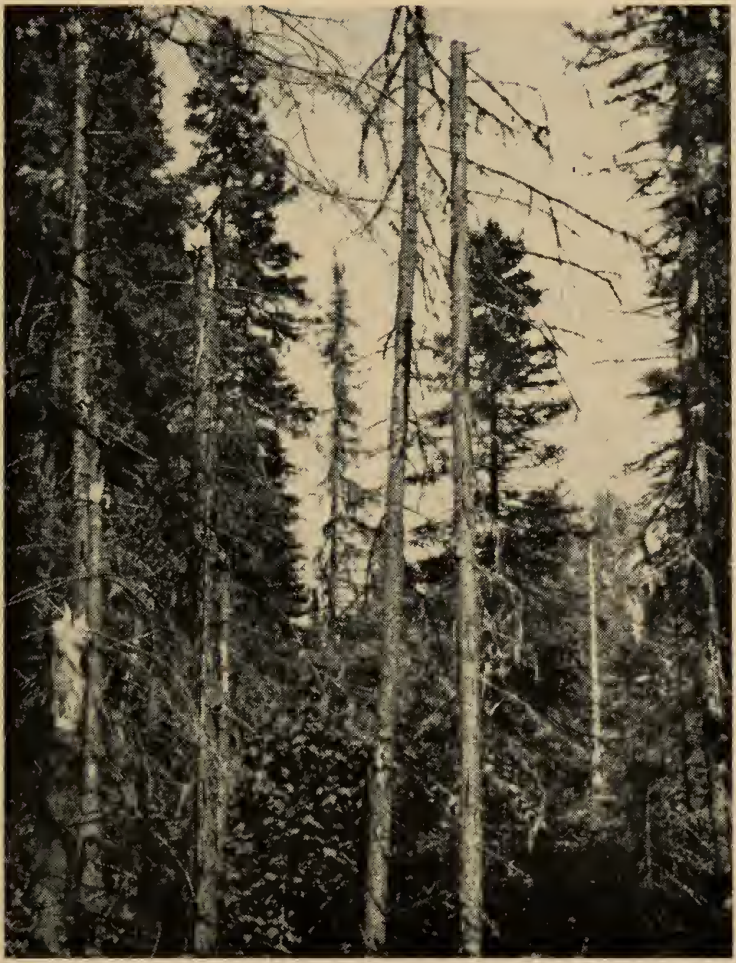

Fig. 35.—Dead balsam fir among large living white spruce (Manitowik Lake, August, 1947).

APPENDIX A

Common and Scientific Names and Symbols for Tree Species Referred to in Text

Common Name	*Scientific Name**	Symbol
Aspen (trembling)	*Populus tremuloides* Michx	A
Balsam Fir	*Abies balsamea* (L.) Mill	Fb
Black Ash	*Fraxinus nigra* Marsh	ASb
Black Spruce	*Picea mariana* (Mill.) BSP	Sb
Ironwood	*Ostrya virginiana* (Mill.) K. Koch	I
Jack Pine	*Pinus Banksiana* Lamb	Pj
Larch; Tamarack	*Larix laricina* (DuRoi) K. Koch	Le
Mountain Ash	*Pyrus decora* (Sarg.) Hyland	ASm
Pin Cherry	*Prunus pensylvanica* L.f	CHp
Red Maple	*Acer rubrum* L	Mr
Red Pine	*Pinus resinosa* Ait	Pr
Sugar Maple	*Acer saccharum* Marsh	Ms
White Birch	*Betula papyrifera* Marsh	Bw
White Cedar (eastern)	*Thuja occidentalis* L	Ce
White Elm	*Ulmus americana* L	Ew
White Pine	*Pinus Strobus* L	Pw
White Spruce	*Picea glauca* (Moench) Voss	Sw
Yellow Birch	*Betula lutea* Michx. f	By

* Nomenclature is after Fernald (11).

APPENDIX B

Stand Tables

Tables 51 to 60 illustrate the forest composition of commonly occurring cover types in Algoma, based on the method of cover-type classification outlined in Table 3. Each table represents the average of several separate tallies taken on plots of similar cover type, and gives the per-acre tree content by number of stems, basal area in square feet at breast height, and the gross total volume in cubic feet by diameter-class groups. The species distribution by percentage of the whole stand, and diameter-class distribution by percentage within each species, are also shown. Species are grouped, by double horizontal lines, into the chief budworm hosts, other conifers, intolerant hardwoods, and tolerant hardwoods.

The stand contents include all dead budworm-host trees whether standing or on the ground, and dead non-budworm-host trees which are standing and intact. Mortality in the latter group is small and, as noted below, is not an important factor in the stands represented. All quantities less than 0·6 in the number and volume columns, and 0·06 in the basal area column are designated by a "+" sign.

The following points were observed when plots were selected to give an average stand table for each classified type.

1. All plots (except those for Table 54) were within the Algoma Section of the Great Lakes-St. Lawrence Forest Region, and if possible, examples of each type were chosen from each of the localities sampled.

2. All plots were at least one-tenth acre.

3. Plots selected had average stocking; not open-grown or excessively dense.

4. All stands were mature (at least 70 years old).

5. Stands were avoided where logging had been recent or noticeable; as far as possible the undisturbed forest condition was sought.

6. In most cases plots were well removed from rivers, lakes, roads or railways.

7. Stands were avoided which had excessive mortality of any species other than budworm hosts.

TABLE 51

Cover Type: S_1Sb Number of Samples: 10 Acres Tallied: 1·725

Number of Stems per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	144	75	42	31	8	—	—	—	300	24
%	48	25	14	10	3	—	—	—		
Sw	1	2	—	1	2	—	—	—	6	+
%	17	33	—	17	33	—	—	—		
Sb	182	138	88	150	94	24	9	—	685	54
%	27	20	13	22	14	3	1	—		
Pw	1	—	—	—	—	+	2	2	5	+
%	20	—	—	—	—	+	40	40		
Ce	37	27	10	20	15	1	1	—	111	9
%	33	24	9	18	14	1	1	—		
Le	75	48	16	3	2	—	—	—	144	11
%	52	34	11	2	1	—	—	—		
Bw	—	4	2	4	6	1	—	—	17	1
%	—	24	12	24	35	6	—	—		
ASm	3	1	—	—	—	—	—	—	4	+
%	75	25	—	—	—	—	—	—		
Mr	1	—	1	—	—	—	—	—	2	+
%	50	—	50	—	—	—	—	—		
Total									1,274	

Basal Area per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	0·9	1·7	2·0	4·2	2·6	—	—	—	11·4	9
%	8	15	17	37	23	—	—	—		
Sw	+	+	—	0·2	0·4	—	—	—	0·6	+
%	+	+	—	33	67	—	—	—		
Sb	1·1	3·0	4·3	21·3	30·7	15·2	8·7	—	84·3	69
%	1	4	5	25	37	18	10	—		
Pw	+	—	—	—	—	0·2	3·8	4·2	8·2	7
%	+	—	—	—	—	3	46	51		
Ce	0·2	0·6	0·5	2·5	4·8	0·7	1·2	—	10·6	9
%	2	6	5	24	45	7	11	—		
Le	0·5	1·0	0·8	0·3	0·6	—	—	—	3·2	2
%	16	31	25	9	19	—	—	—		
Bw	—	0·1	0·1	0·4	2·3	0·8	—	—	3·7	3
%	—	3	3	11	62	21	—	—		
ASm	+	+	—	—	—	—	—	—	+	+
%	45	55	—	—	—	—	—	—		
Mr	+	—	+	—	—	—	—	—	0·1	+
%	11	—	89	—	—	—	—	—		
Total									122·1	

Total Volume per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	5	13	22	70	54	—	—	—	164	6
%	3	8	13	43	33	—	—	—		
Sw	+	+	—	2	8	—	—	—	10	+
%	+	+	—	20	80	—	—	—		
Sb	5	21	41	341	675	417	275	—	1,775	70
%	+	1	2	19	38	24	16	—		
Pw	+	—	—	—	—	7	145	162	314	12
%	+	—	—	—	—	2	46	52		
Ce	1	7	5	31	75	13	25	—	157	6
%	1	4	3	20	48	8	16	—		
Le	2	8	8	4	12	—	—	—	34	1
%	6	24	24	12	35	—	—	—		
Bw	—	2	2	9	58	20	—	—	91	4
%	—	2	2	10	64	22	—	—		
ASm	+	+	—	—	—	—	—	—	1	+
%	35	65	—	—	—	—	—	—		
Mr	+	—	1	—	—	—	—	—	1	+
%	9	—	91	—	—	—	—	—		
Total									2,547	

TABLE 52

Cover Type: S_1C (flat, low) Number of Samples: 11 Acres Tallied: 2·275

Sp.	Number of Stems per Acre										Basal Area per Acre										Total Volume per Acre									
	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	101	66	42	43	12	8	—	—	272	26	0·6	1·4	2·0	5·3	4·5	4·4	—	—	18·3	13	4	11	22	81	100	115	—	—	333	13
%	37	24	16	16	4	3	—	—			3	8	11	29	25	24	—	—			1	3	7	24	30	35	—	—		
Sw	5	8	+	4	2	+	1	—	20	2	+	0·2	+	0·4	0·6	0·1	0·7	—	2·0	1	+	1	+	5	13	3	18	—	40	1
%	25	40	+	20	10	+	5	—			+	10	+	20	30	5	35	—			+	3	+	12	33	7	45	—		
Sb	22	15	17	35	28	7	+	—	124	12	0·1	0·3	0·9	4·7	9·5	3·9	0·3	—	19·7	14	1	2	8	70	199	99	8	—	387	15
%	18	12	14	28	22	6	+	—			1	1	5	24	48	20	1	—			+	1	2	18	51	26	2	—		
Pw	+	—	—	—	—	+	—	—	+	+	+	—	—	—	—	0·2	—	—	0·2	+	+	—	—	—	—	5	—	—	5	+
%	75	—	—	—	—	25	—	—			1	—	—	—	—	99	—	—			+	—	—	—	—	100	—	—		
Ce	170	77	64	96	55	31	22	5	520	50	1·0	1·7	3·1	12·5	18·2	20·1	27·1	10·5	94·2	65	5	19	29	156	293	363	549	238	1,652	63
%	33	15	12	18	11	6	4	1			1	2	3	13	19	22	29	11			+	1	2	10	18	22	33	14		
Le	36	12	8	8	+	—	+	—	64	6	0·2	0·3	0·4	0·9	0·2	—	0·3	—	2·3	1	1	2	4	13	3	—	11	—	34	1
%	56	19	12	12	+	—	+	—			9	13	17	39	9	—	13	—			3	6	12	38	9	—	32	—		
Bw	6	1	1	3	1	5	—	—	17	2	+	+	0·1	0·4	0·7	3·4	—	—	4·6	3	+	+	1	11	18	87	—	—	118	4
%	35	6	6	18	6	29	—	—			+	+	2	9	15	74	—	—			+	+	1	9	15	74	—	—		
A	1	—	1	—	—	—	—	—	2	+	+	—	+	—	—	—	—	—	+	+	+	—	+	—	—	—	—	—	+	+
%	50	—	50	—	—	—	—	—			11	—	89	—	—	—	—	—			6	—	94	—	—	—	—	—		
ASm	2	—	—	—	—	—	—	—	2	+	+	—	—	—	—	—	—	—	+	+	+	—	—	—	—	—	—	—	+	+
%	100	—	—	—	—	—	—	—			100	—	—	—	—	—	—	—			100	—	—	—	—	—	—	—		
By	2	2	3	2	—	—	2	—	11	1	+	+	0·2	0·2	—	—	1·9	—	2·4	2	+	+	2	4	—	—	58	—	64	2
%	18	18	27	18	—	—	18	—			+	2	8	10	—	—	79	—			+	+	3	6	—	—	91	—		
Ms	+	—	—	—	—	—	—	—	+	+	+	—	—	—	—	—	—	—	+	+	+	—	—	—	—	—	—	—	+	+
%	100	—	—	—	—	—	—	—			100	—	—	—	—	—	—	—			100	—	—	—	—	—	—	—		
Mr	1	—	2	—	—	—	—	—	3	+	+	—	0·1	—	—	—	—	—	0·1	+	+	—	1	—	—	—	—	—	1	+
%	37	—	63	—	—	—	—	—			6	—	94	—	—	—	—	—			5	—	95	—	—	—	—	—		
ASb	—	—	2	—	+	—	—	—	2	+	—	—	0·1	—	0·1	—	—	—	0·2	+	—	—	1	—	3	—	—	—	4	+
%	—	—	80	—	20	—	—	—			—	—	42	—	58	—	—	—			—	—	29	—	71	—	—	—		
Total									1,037										144·0										2,638	

TABLE 53

Cover Type: S_2Fb Number of Samples: 15 Acres Tallied: 3·700

Number of Stems per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
	Diameter-class Groups									
Fb	207	179	144	215	88	16	4	—	853	79
%	24	21	17	25	10	2	+	—		
Sw	12	12	11	14	12	3	2	—	66	6
%	18	18	17	21	18	4	3	—		
Sb	2	3	2	11	7	3	—	—	28	3
%	7	11	7	39	25	11	—	—		
Pw	+	1	1	1	1	+	1	3	8	1
%	+	12	12	12	12	+	12	38		
Pj	—	—	—	—	—	1	+	—	1	+
%	—	—	—	—	—	83	17	—		
Ce	3	—	1	+	1	1	1	—	7	+
%	43	—	14	+	14	14	14	—		
Le	+	+	+	1	+	—	—	—	2	+
%	15	11	18	44	11	—	—	—		
Bw	9	8	16	16	11	5	7	+	72	7
%	13	11	22	22	15	7	10	+		
A	+	1	1	4	4	1	—	—	12	1
%	+	8	8	33	33	8	—	—		
CHp	2	—	+	—	—	—	—	—	2	+
%	79	—	21	—	—	—	—	—		
ASm	12	3	1	—	—	—	—	—	16	1
%	77	19	4	—	—	—	—	—		
By	—	+	1	1	+	—	—	—	2	+
%	—	13	30	35	22	—	—	—		
Mr	7	+	1	1	—	—	—	—	9	1
%	76	5	12	7	—	—	—	—		
Total									1,078	

Basal Area per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
	Diameter-class Groups									
Fb	1·2	3·9	7·1	26·9	28·5	9·5	4·3	—	81·4	60
%	1	5	9	33	35	12	5	—		
Sw	0·1	0·2	0·5	1·7	4·2	1·9	2·5	—	11·1	8
%	1	2	4	15	38	17	23	—		
Sb	+	0·1	0·1	1·5	2·4	1·9	—	—	6·0	4
%	+	2	2	25	40	31	—	—		
Pw	+	+	+	0·2	0·4	0·1	1·0	8·4	10·1	8
%	+	+	+	2	4	1	10	83		
Pj	—	—	—	—	—	0·5	0·1	—	0·6	+
%	—	—	—	—	—	79	21	—		
Ce	+	—	+	+	0·4	0·4	1·3	—	2·1	2
%	+	—	+	+	19	19	62	—		
Le	+	+	+	0·1	0·1	—	—	—	0·2	+
%	+	2	7	57	34	—	—	—		
Bw	0·1	0·2	0·7	1·9	4·1	3·6	8·5	0·9	20·0	15
%	+	1	4	10	20	18	42	4		
A	+	+	0·1	0·5	1·2	0·6	—	—	2·4	2
%	+	+	4	21	50	25	—	—		
CHp	+	+	+	—	—	—	—	—	+	+
%	30	+	70	—	—	—	—	—		
ASm	0·1	0·1	+	—	—	—	—	—	0·2	+
%	43	38	19	—	—	—	—	—		
By	—	+	+	0·1	0·1	—	—	—	0·3	+
%	—	2	8	32	58	—	—	—		
Mr	+	+	+	0·1	—	—	—	—	0·2	+
%	24	6	30	40	—	—	—	—		
Total									134·6	

Total Volume per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
	Diameter-class Groups									
Fb	7	31	77	419	607	234	127	—	1.502	51
%	+	2	5	28	40	16	9	—		
Sw	+	2	5	24	88	50	85	—	254	9
%	+	+	2	9	35	20	33	—		
Sb	+	+	1	23	56	49	—	—	130	4
%	+	+	1	18	43	38	—	—		
Pw	+	+	+	2	8	4	38	345	398	14
%	+	+	+	+	2	1	10	87		
Pj	—	—	—	—	—	14	4	—	18	1
%	—	—	—	—	—	78	22	—		
Ce	+	—	+	+	6	7	25	—	39	1
%	+	—	1	1	15	18	64	—		
Le	+	+	+	2	2	—	—	—	4	+
%	+	1	3	54	41	—	—	—		
Bw	1	3	17	46	103	93	220	25	508	17
%	+	1	3	9	20	18	44	5		
A	+	+	1	10	30	17	—	—	58	2
%	+	+	2	17	52	29	—	—		
CHp	+	—	1	—	—	—	—	—	1	+
%	20	—	80	—	—	—	—	—		
ASm	1	1	1	—	—	—	—	—	3	+
%	33	42	25	—	—	—	—	—		
By	—	+	+	1	4	—	—	—	5	+
%	—	1	5	26	68	—	—	—		
Mr	+	+	1	1	—	—	—	—	2	+
%	17	5	29	49	—	—	—	—		
Total									2,922	

TABLE 54

Cover Type: S_2Pw (mature, undisturbed) Timagami Forest Section Number of Samples: 7 Acres Tallied: 1·200

Number of Stems per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	101	118	88	99	43	7	—	—	456	64
%	22	26	19	22	9	2	—	—		
Sw	10	9	5	2	3	2	3	—	34	5
%	29	26	15	6	9	6	9	—		
Sb	3	3	—	2	4	—	1	—	13	2
%	23	23	—	15	31	—	8	—		
Pw	1	—	—	1	7	13	38	24	84	12
%	1	—	—	1	8	16	45	29		
Pr	—	—	—	—	—	1	+	—	1	+
%	—	—	—	—	—	67	33	—		
Pj	—	—	—	—	—	1	3	—	4	+
%	—	—	—	—	—	23	77	—		
Ce	—	—	2	3	1	4	2	—	12	2
%	—	—	17	25	8	33	17	—		
Bw	3	—	+	8	15	26	11	+	63	9
%	4	—	+	13	24	41	17	+		
A	1	—	—	—	—	—	3	—	4	+
%	34	—	—	—	—	—	66	—		
ASm	10	—	+	1	—	—	—	—	12	2
%	85	—	2	12	—	—	—	—		
Mr	18	6	1	2	—	—	—	—	27	4
%	67	22	4	7	—	—	—	—		
Total									710	

Basal Area per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	0·6	2·6	4·4	13·7	13·3	4·4	—	—	39·0	17
%	2	7	11	35	34	11	—	—		
Sw	0·1	0·2	0·2	0·2	0·9	1·6	3·5	—	6·7	3
%	2	3	3	3	13	24	52	—		
Sb	+	0·1	—	0·2	1·4	—	2·0	—	3·7	2
%	+	2	—	6	38	—	54	—		
Pw	+	—	—	0·2	2·8	7·6	55·5	60·6	126·7	56
%	+	—	—	+	2	6	44	48		
Pr	—	—	—	—	—	0·5	0·4	—	0·9	+
%	—	—	—	—	—	51	49	—		
Pj	—	—	—	—	—	0·6	3·8	—	4·4	2
%	—	—	—	—	—	14	86	—		
Ce	—	—	0·1	0·5	0·5	2·3	2·0	—	5·4	2
%	—	—	1	9	9	44	37	—		
Bw	+	—	+	1·5	5·2	17·7	11·5	0·8	36·7	16
%	+	—	+	4	14	48	31	2		
A	+	—	—	—	—	—	3·1	—	3·1	1
%	+	—	—	—	—	—	100	—		
ASm	0·1	—	+	0·3	—	—	—	—	0·4	+
%	17	—	5	78	—	—	—	—		
Mr	0·1	0·1	0·1	0·3	—	—	—	—	0·6	+
%	19	23	12	46	—	—	—	—		
Total									227·6	

Total Volume per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	4	20	46	221	274	114	—	—	679	10
%	1	3	7	32	40	17	—	—		
Sw	+	2	2	4	19	49	123	—	199	3
%	+	1	1	2	9	25	62	—		
Sb	+	+	—	3	34	—	72	—	109	2
%	+	+	—	3	31	—	66	—		
Pw	+	—	—	2	66	221	2067	2433	4,789	67
%	+	—	—	+	1	5	43	51		
Pr	—	—	—	—	—	14	16	—	30	+
%	—	—	—	—	—	47	53	—		
Pj	—	—	—	—	—	17	120	—	137	2
%	—	—	—	—	—	12	88	—		
Ce	—	—	1	6	8	42	39	—	96	1
%	—	—	1	6	8	44	41	—		
Bw	+	—	+	36	132	454	298	20	940	13
%	+	—	+	4	14	48	32	2		
A	+	—	—	—	—	—	101	—	101	1
%	+	—	—	—	—	—	100	—		
ASm	1	—	+	7	—	—	—	—	8	+
%	10	—	5	86	—	—	—	—		
Mr	1	1	1	4	—	—	—	—	7	+
%	13	18	11	58	—	—	—	—		
Total									7,095	

TABLE 55

Cover Type: SHI_{FS} Number of Samples: 24 Acres Tallied: 3·800

Number of Stems per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
	Diameter-class Groups									
Fb	137	91	77	130	70	14	2	—	521	61
%	26	18	15	25	13	3	+	—		
Sw	7	8	12	17	12	5	2	1	64	7
%	11	12	19	26	19	8	3	2		
Sb	3	5	3	3	3	1	—	—	18	2
%	17	28	17	17	17	5	—	—		
Pw	1	3	1	7	5	+	2	1	20	2
%	5	15	5	35	25	+	10	5		
Pr	—	—	—	+	—	—	—	—	+	+
%	—	—	—	100	—	—	—	—		
Pj	—	—	—	—	—	+	+	—	+	+
%	—	—	—	—	—	22	78	—		
Ce	10	3	2	1	3	3	1	—	23	3
%	44	13	9	4	13	13	4	—		
Le	—	—	—	—	10	—	—	—	10	1
%	—	—	—	—	100	—	—	—		
Bw	15	11	12	23	29	14	13	3	120	14
%	13	9	10	19	24	12	11	2		
A	1	—	+	5	10	2	+	—	19	2
%	5	—	3	26	53	11	1	—		
CHp	5	1	+	1	—	—	—	—	7	1
%	68	22	3	6	—	—	—	—		
ASm	15	2	+	1	—	—	—	—	18	2
%	80	13	2	4	—	—	—	—		

Basal Area per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
	Diameter-class Groups									
Fb	0·8	2·0	3·8	16·9	23·1	9·1	2·8	—	58·5	41
%	1	3	6	29	40	16	5	—		
Sw	+	0·2	0·6	2·4	3·8	3·2	2·9	1·9	15·0	10
%	+	1	4	16	25	22	19	13		
Sb	+	0·1	0·2	0·4	1·2	0·3	—	—	2·2	2
%	+	5	9	18	54	14	—	—		
Pw	+	0·1	0·1	0·9	1·6	0·3	1·8	3·6	8·4	6
%	+	1	1	11	19	4	21	43		
Pr	—	—	—	+	—	—	—	—	+	+
%	—	—	—	100	—	—	—	—		
Pj	—	—	—	—	—	0·1	0·4	—	0·5	+
%	—	—	—	—	—	16	84	—		
Ce	0·1	0·1	0·1	0·1	1·0	1·9	1·3	—	4·6	3
%	2	2	2	2	22	41	28	—		
Le	—	—	—	—	0·1	—	—	—	0·1	+
%	—	—	—	—	100	—	—	—		
Bw	0·1	0·3	0·6	3·4	9·5	9·2	16·5	6·0	45·6	32
%	+	1	1	8	21	20	36	13		
A	+	—	+	0·8	3·3	1·5	0·2	—	5·8	4
%	+	—	+	14	57	26	3	—		
CHp	+	+	+	0·1	—	—	—	—	0·1	+
%	21	26	8	44	—	—	—	—		
ASm	0·1	0·1	+	0·1	—	—	—	—	0·3	+
%	32	19	7	42	—	—	—	—		

Total Volume per Acre

Sp.	1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
	Diameter-class Groups									
Fb	5	16	40	269	483	235	78	—	1126	24
%	+	1	4	24	43	21	7	—		
Sw	+	1	6	37	83	87	97	70	381	12
%	+	+	2	10	22	23	25	18		
Sb	+	1	1	7	26	7	—	—	42	1
%	+	2	2	17	62	17	—	—		
Pw	+	+	1	12	34	10	68	145	270	8
%	+	+	+	4	13	4	25	54		
Pr	—	—	—	+	—	—	—	—	+	+
%	—	—	—	100	—	—	—	—		
Pj	—	—	—	—	—	2	13	—	15	+
%	—	—	—	—	—	15	85	—		
Ce	+	1	1	1	17	35	27	—	82	3
%	+	1	1	1	21	43	33	—		
Le	—	—	—	—	2	—	—	—	2	+
%	—	—	—	—	100	—	—	—		
Bw	1	5	13	83	237	238	428	155	1,160	35
%	+	+	1	7	20	21	37	13		
A	+	—	+	17	87	44	7	—	155	5
%	+	—	+	11	56	28	5	—		
CHp	+	1	+	1	—	—	—	—	3	+
%	14	24	9	54	—	—	—	—		
ASm	1	1	+	3	—	—	—	—	5	+
%	20	18	8	53	—	—	—	—		

By	—	—	+	1	—	+	+	—	1	+	—	—	+	0·1	—	0·2	0·2	—	0·6	+	—	—	+	2	—	6	7	—	15	+
%	—	—	24	48	—	19	10	—			—	—	4	20	—	36	40	—			—	—	2	12	—	38	49	—		
Ms	1	1	+	—	1	—	—	—	3	+	+	+	+	—	0·2	—	—	—	0·2	+	+	+	+	—	4	—	—	—	5	+
%	53	19	7	—	21	—	—	—			4	5	4	—	86	—	—	—			2	3	3	—	93	—	—	—		
Mr	14	5	6	6	1	—	—	—	32	4	0·1	0·1	0·3	0·8	0·3	—	—	—	1·6	1	1	1	4	13	6	—	—	—	25	1
%	44	15	19	19	3	—	—	—			6	6	19	50	19	—	—	—			4	4	16	52	24	—	—	—		
Total									856										143·5										3,286	

TABLE 56

Cover Type: SHT_{FS} Number of Samples: 13 Acres Tallied: 2·110

Number of Stems per Acre

Sp.	Diameter-class Groups 1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	92	60	41	67	50	22	3	—	335	54
Fb %	27	18	12	20	15	7	1	—		
Sw	4	6	3	7	5	5	7	1	38	6
Sw %	11	16	8	18	13	13	18	3		
Sb	—	—	—	—	—	—	+	—	+	+
Sb %	—	—	—	—	—	—	100	—		
Pw	—	—	—	+	—	—	—	—	+	+
Pw %	—	—	—	100	—	—	—	—		
Ce	6	2	5	12	8	4	9	1	47	8
Ce %	13	4	11	26	17	9	19	2		
Bw	9	7	3	6	3	1	4	1	34	6
Bw %	26	21	9	17	9	3	12	3		
Ew	—	1	—	1	—	—	—	—	2	+
Ew %	—	33	—	67	—	—	—	—		
CHp	2	1	1	1	—	—	—	—	5	1
CHp %	42	29	9	20	—	—	—	—		
ASm	10	3	3	—	—	—	—	—	16	3
ASm %	60	22	18	—	—	—	—	—		
By	10	6	5	5	8	8	12	7	61	10
By %	16	10	8	8	13	13	20	12		
Ms	21	8	4	3	4	5	1	+	46	7
Ms %	45	17	9	7	9	11	2	+		
Mr	21	3	3	4	2	—	—	—	33	5
Mr %	64	9	9	12	6	—	—	—		
Total									617	

Basal Area per Acre

Sp.	Diameter-class Groups 1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	0·6	1·3	2·0	8·9	17·0	14·0	3·5	—	47·3	32
Fb %	1	3	4	19	36	30	7	—		
Sw	+	0·1	0·1	0·1	1·8	3·1	8·7	3·5	18·3	12
Sw %	+	1	1	5	10	17	47	19		
Sb	—	—	—	—	—	—	0·3	—	0·3	+
Sb %	—	—	—	—	—	—	100	—		
Pw	—	—	—	+	—	—	—	—	+	+
Pw %	—	—	—	100	—	—	—	—		
Ce	+	0·1	0·3	1·8	2·8	2·6	12·4	1·4	21·4	15
Ce %	+	+	1	8	13	12	58	7		
Bw	0·1	0·1	0·1	0·8	1·1	1·0	5·0	1·4	9·6	6
Bw %	1	1	1	8	12	10	52	15		
Ew	—	+	—	0·2	—	—	—	—	0·2	+
Ew %	—	8	—	92	—	—	—	—		
CHp	+	+	+	0·1	—	—	—	—	0·2	+
CHp %	8	21	14	57	—	—	—	—		
ASm	0·1	0·1	0·1	—	—	—	—	—	0·3	+
ASm %	21	28	51	—	—	—	—	—		
By	0·1	0·1	0·2	0·7	2·9	5·4	15·7	15·8	40·9	28
By %	+	+	+	2	7	13	38	39		
Ms	0·1	0·2	0·2	0·4	1·4	3·0	1·4	0·8	7·5	5
Ms %	1	3	3	5	19	40	19	10		
Mr	0·1	0·1	0·1	0·4	0·6	0·2	—	—	1·5	1
Mr %	8	5	8	26	42	11	—	—		
Total									147·5	

Total Volume per Acre

Sp.	Diameter-class Groups 1	2	3	4–6	7–9	10–12	13–18	19+	Total	% of Stand
Fb	3	10	22	143	367	365	99	—	1,009	27
Fb %	+	1	2	14	36	36	10	—		
Sw	+	1	1	16	41	91	298	127	575	16
Sw %	+	+	+	3	7	16	52	22		
Sb	—	—	—	—	—	—	8	—	8	+
Sb %	—	—	—	—	—	—	100	—		
Pw	—	—	—	1	—	—	—	—	1	+
Pw %	—	—	—	100	—	—	—	—		
Ce	+	1	2	24	46	47	261	32	413	11
Ce %	+	+	+	6	11	11	63	8		
Bw	1	3	3	19	29	25	129	36	245	7
Bw %	+	1	1	8	12	10	53	15		
Ew	—	+	—	3	—	—	—	—	3	+
Ew %	—	5	—	95	—	—	—	—		
CHp	+	1	+	2	—	—	—	—	3	+
CHp %	5	18	14	63	—	—	—	—		
ASm	1	1	3	—	—	—	—	—	5	+
ASm %	14	27	59	—	—	—	—	—		
By	+	1	3	12	63	147	479	501	1.206	33
By %	+	+	+	1	5	12	40	42		
Ms	1	2	2	7	30	71	35	19	167	4
Ms %	1	1	1	4	18	43	21	11		
Mr	1	1	2	6	14	4	—	—	28	1
Mr %	4	3	6	22	50	15	—	—		
Total									3,663	

TABLE 57

Cover Type: HSI_{FS} Number of Samples: 17 Acres Tallied 2·625

Sp.	Number of Stems per Acre										Basal Area per Acre										Total Volume per Acre									
	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	132	122	77	82	49	12	+	—	475	51	0·8	2·7	3·8	11·1	15·4	7·8	0·5	—	42·1	28	4	21	40	180	322	203	14	—	784	2
%	28	26	16	17	10	3	+	—			2	6	9	26	37	19	1	—			+	3	5	23	41	26	2	—		
Sw	5	14	9	16	7	5	2	—	58	6	+	0·3	0·5	2·2	2·6	3·0	2·2	—	10·8	7	+	2	5	36	59	80	68	—	250	7
%	8	24	16	28	12	9	3	—			+	3	5	20	24	28	20	—			+	1	2	14	24	32	27	—		
Sb	1	1	3	2	2	1	—	—	10	1	+	+	0·1	0·3	0·8	0·4	—	—	1·7	1	+	+	1	5	17	12	—	—	35	1
%	10	10	30	20	20	10	—	—			+	2	8	18	47	24	—	—			+	+	3	14	49	34	—	—		
Pw	—	2	1	1	1	+	1	—	6	1	—	+	0·1	0·1	0·2	0·2	1·0	—	1·7	1	—	+	1	1	5	6	37	—	50	1
%	—	33	17	17	17	+	17	—			—	3	6	6	12	12	61	—			—	+	2	2	10	12	74	—		
Pr	—	—	—	—	+	—	—	—	+	+	—	—	—	—	0·8	—	—	—	0·8	+	—	—	—	—	2	—	—	—	2	+
%	—	—	—	—	100	—	—	—			—	—	—	—	100	—	—	—			—	—	—	—	100	—	—	—		
Pj	—	—	—	+	1	1	+	—	2	+	—	—	—	+	0·3	0·4	0·4	—	1·1	1	—	—	—	1	7	11	11	—	30	1
%	—	—	—	22	36	22	19	—			—	—	—	6	27	34	33	—			—	—	—	4	25	36	36	—		
Ce	1	—	—	1	—	—	+	+	2	+	+	—	—	0·1	—	—	0·3	0·7	1·1	1	+	—	—	2	—	—	5	16	23	1
%	24	—	—	42	—	—	15	18			+	—	—	11	—	—	24	64			+	—	—	7	—	—	21	71		
Bw	11	29	34	49	52	31	14	+	221	24	0·2	1·1	2·3	7·1	18·6	20·3	17·8	1·3	68·7	45	4	23	52	174	467	524	460	33	1,737	50
%	5	13	15	22	24	14	6	+			+	2	3	10	27	30	26	2			+	1	3	10	27	30	27	2		
A	1	6	3	20	18	8	3	—	59	6	+	0·1	0·2	2·7	6·2	5·1	3·6	—	17·9	12	+	1	2	55	164	154	116	—	493	14
%	2	10	5	34	30	14	5	—			+	1	1	15	35	28	20	—			+	+	+	11	33	31	24	—		
CHp	1	+	1	—	—	—	—	—	2	+	+	+	+	—	—	—	—	—	+	+	+	+	1	—	—	—	—	—	1	+
%	64	18	18	—	—	—	—	—			23	24	53	—	—	—	—	—			15	23	62	—	—	—	—	—		
ASm	7	1	1	+	—	—	—	—	10	1	+	+	0·1	+	—	—	—	—	0·1	+	1	+	1	+	—	—	—	—	3	+
%	79	6	12	2	—	—	—	—			33	10	43	14	—	—	—	—			22	10	51	18	—	—	—	—		
By	—	—	+	1	1	+	+	—	2	+	—	—	+	0·1	0·2	0·2	0·4	—	0·9	1	—	—	+	1	5	5	11	—	22	1
%	—	—	24	27	24	12	12	—			—	—	3	8	24	23	42	—			—	—	+	4	21	24	50	—		
Ms	24	6	4	4	1	+	1	—	40	4	0·1	0·1	0·2	0·6	0·2	0·2	0·5	—	1·9	1	1	1	3	9	5	4	13	—	36	1
%	60	15	10	10	2	+	2	—			5	5	11	31	11	11	26	—			3	3	8	25	14	11	36	—		
Mr	22	11	6	3	3	+	—	—	46	5	0·1	0·3	0·3	0·4	1·0	0·1	—	—	2·2	1	1	3	4	6	21	3	—	—	38	1
%	48	24	13	7	7	+	—	—			4	14	14	18	45	4	—	—			3	8	10	16	55	8	—	—		
Total									933										151·0										3,504	

TABLE 58

Cover Type: HST_{FS} Number of Samples: 11 Acres Tallied: 1·475

Sp.	Number of Stems per Acre										Basal Area per Acre										Total Volume per Acre									
	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	80	55	33	37	36	10	1	—	252	33	0·5	1·2	1·6	5·1	11·6	6·4	1·4	—	27·8	19	3	10	17	83	245	164	38	—	560	16
%	32	22	13	15	14	4	+	—			2	4	6	18	42	23	5	—			1	2	3	15	43	29	7	—		
Sw	15	10	4	12	8	4	1	—	54	7	0·1	0·2	0·2	1·7	3·1	2·5	1·6	—	9·4	7	+	2	2	26	73	70	50	—	223	6
%	28	19	7	22	15	7	2	—			1	2	2	18	33	27	17	—			+	1	1	12	33	31	22	—		
Sb	1	+	—	—	—	—	—	—	1	+	+	+	—	—	—	—	—	—	+	+	+	+	—	—	—	—	—	—	+	+
%	59	41	—	—	—	—	—	—			29	71	—	—	—	—	—	—			21	79	—	—	—	—	—	—		
Pw	—	—	—	—	—	—	—	1	1	+	—	—	—	—	—	—	—	2·1	2·1	1	—	—	—	—	—	—	—	88	88	3
%	—	—	—	—	—	—	—	100			—	—	—	—	—	—	—	100			—	—	—	—	—	—	—	100		
Ce	15	5	2	3	3	4	4	—	36	5	0·1	0·1	0·1	0·5	1·2	2·2	3·5	—	7·7	5	+	1	1	6	19	40	68	—	135	4
%	42	14	6	8	8	11	11	—			1	1	1	6	16	29	46	—			+	1	1	4	14	30	50	—		
Bw	5	2	3	4	10	2	3	1	30	4	+	+	0·1	0·7	3·6	1·0	3·9	2·8	12·1	8	+	1	3	17	89	25	100	73	308	9
%	17	7	10	13	33	7	10	3			+	+	1	6	30	8	32	23			+	+	1	6	29	8	32	24		
ASm	3	2	1	—	—	—	—	—	6	1	+	+	+	—	—	—	—	—	0·1	+	+	1	1	—	—	—	—	—	2	+
%	58	33	9	—	—	—	—	—			23	48	29	—	—	—	—	—			16	49	36	—	—	—	—	—		
By	11	5	1	3	3	6	9	7	45	6	0·1	0·1	0·1	0·4	1·0	4·3	10·5	17·1	33·6	24	1	1	1	7	22	119	316	544	1,011	30
%	24	11	2	7	7	13	20	16			+	+	+	1	3	13	31	51			+	+	+	1	2	12	31	54		
Ms	155	40	14	27	17	18	19	1	291	38	0·9	0·9	0·7	3·7	6·2	11·3	22·1	1·8	47·6	33	9	9	8	63	132	283	543	44	1,091	31
%	53	14	5	9	6	6	7	+			2	2	1	8	13	24	46	4			1	1	1	6	12	26	50	4		
Mr	17	10	4	7	1	1	—	—	40	5	0·1	0·2	0·2	1·0	0·3	0·6	—	—	2·4	2	1	2	3	17	7	14	—	—	44	1
%	43	25	10	18	2	2	—	—			4	8	8	42	13	25	—	—			2	4	7	39	16	32	—	—		
Total									756										142·8										3,462	

TABLE 59

Cover Type: H_2I Number of Samples: 5 Acres Tallied: 0·750

Sp.	Number of Stems per Acre										Basal Area per Acre										Total Volume per Acre									
	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+			1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	41	22	17	15	12	—	—	—	107	13	0·2	0·5	0·8	1·6	3·9	—	—	—	7·0	5	1	4	9	24	80	—	—	—	118	3
%	38	21	16	14	11	—	—	—			3	7	11	23	56	—	—	—			1	3	8	20	68	—	—	—		
Sw	4	4	2	—	—	—	—	—	10	1	+	0·1	0·1	—	—	—	—	—	0·2	+	+	1	1	—	—	—	—	—	2	+
%	43	41	16	—	—	—	—	—			13	45	42	—	—	—	—	—			8	42	50	—	—	—	—	—		
Sb	1	—	—	—	—	—	—	—	1	+	+	—	—	—	—	—	—	—	+	+	+	—	—	—	—	—	—	—	+	+
%	100	—	—	—	—	—	—	—			100	—	—	—	—	—	—	—			100	—	—	—	—	—	—	—		
Pw	—	—	—	1	1	—	—	—	2	+	—	—	—	0·2	0·2	—	—	—	0·4	+	—	—	—	3	4	—	—	—	7	+
%	—	—	—	70	30	—	—	—			—	—	—	55	45	—	—	—			—	—	—	50	50	—	—	—		
Pj	—	—	—	—	—	3	—	—	3	+	—	—	—	—	—	1·5	—	—	1·5	1	—	—	—	—	—	40	—	—	40	1
%	—	—	—	—	—	100	—	—			—	—	—	—	—	100	—	—			—	—	—	—	—	100	—	—		
Ce	15	1	3	2	1	—	—	—	22	3	0·1	+	0·1	0·2	0·4	—	—	—	0·8	1	+	+	1	2	6	—	—	—	10	+
%	68	4	14	9	4	—	—	—			12	3	19	22	45	—	—	—			5	3	14	20	58	—	—	—		
Bw	—	7	15	60	68	17	11	3	181	21	—	0·1	0·8	9·7	22·5	10·9	13·5	5·9	63·4	42	—	3	17	236	565	280	350	153	1,604	46
%	—	4	8	33	38	9	6	2			—	+	1	15	36	17	21	9			—	+	1	15	35	17	22	10		
A	—	—	—	11	29	15	6	—	61	7	—	—	—	2·1	9·6	12·1	7·6	—	31·4	21	—	—	—	46	251	304	250	—	851	24
%	—	—	—	18	47	25	10	—			—	—	—	7	31	38	24	—			—	—	—	5	30	36	29	—		
CHp	—	4	4	2	—	—	—	—	10	1	—	0·1	0·2	0·2	—	—	—	—	0·5	+	—	2	4	4	—	—	—	—	10	+
%	—	40	40	20	—	—	—	—			—	19	43	38	—	—	—	—			—	16	43	40	—	—	—	—		
ASm	18	8	4	—	—	—	—	—	30	4	0·1	0·2	0·2	—	—	—	—	—	0·5	+	1	3	4	—	—	—	—	—	9	+
%	60	27	13	—	—	—	—	—			22	37	41	—	—	—	—	—			15	37	48	—	—	—	—	—		
By	1	1	1	3	4	5	5	—	20	2	+	+	+	0·3	1·2	3·1	5·7	—	10·3	7	+	+	1	4	26	82	171	—	284	8
%	5	5	5	15	20	25	25	—			+	+	+	3	12	30	55	—			+	+	+	1	9	29	60	—		
Ms	69	71	70	82	38	1	—	—	331	39	0·4	1·6	3·4	10·7	11·4	0·7	—	—	28·2	19	4	16	43	181	233	17	—	—	494	14
%	21	21	21	25	12	+	—	—			1	6	12	38	41	2	—	—			1	3	9	37	47	3	—	—		
Mr	13	5	13	26	2	—	—	—	59	7	0·1	0·1	0·6	3·6	0·5	—	—	—	4·9	3	1	1	8	61	11	—	—	—	82	2
%	22	9	22	44	3	—	—	—			2	2	12	74	10	—	—	—			1	1	10	74	14	—	—	—		
I	—	1	1	5	—	—	—	—	7	1	—	+	0·1	0·6	—	—	—	—	0·7	+	—	+	1	10	—	—	—	—	11	+
%	—	19	19	62	—	—	—	—			—	4	9	87	—	—	—	—			—	3	7	90	—	—	—	—		
Total									844										149·8										3,522	

TABLE 60

Cover Type: H_2T Number of Samples: 10 Acres Tallied: 1·750

Sp.	Number of Stems per Acre									
	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	36	14	13	9	4	2	—	—	78	10
%	47	18	16	12	4	3	—	—		
Sw	6	3	—	2	2	—	+	—	13	2
%	46	23	—	15	15	—	+	—		
Sb	—	—	—	—	—	—	—	—	—	—
%	—	—	—	—	—	—	—	—		
Pw	+	—	—	—	—	—	—	—	+	+
%	100	—	—	—	—	—	—	—		
Ce	+	+	1	+	+	1	—	—	3	+
%	12	12	24	12	12	29	—	—		
Bw	—	—	1	2	3	4	8	+	18	2
%	—	—	6	11	17	22	44	+		
A	—	—	—	—	—	—	2	—	2	+
%	—	—	—	—	—	—	100	—		
Ew	2	1	+	1	—	—	+	—	5	1
%	42	21	8	21	—	—	8	—		
ASm	1	1	—	2	2	—	—	—	6	1
%	17	17	—	33	33	—	—	—		
By	6	3	4	8	7	9	11	10	58	8
%	10	5	7	14	12	16	19	17		
Ms	344	61	23	34	38	22	30	1	553	74
%	62	11	4	6	7	4	5	+		
Mr	3	3	1	+	—	+	—	—	7	1
%	39	39	11	6	—	6	—	—		
I	5	—	1	+	2	—	—	—	8	1
%	66	—	8	5	21	—	—	—		
Total									751	

Sp.	Basal Area per Acre									
	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	0·2	0·3	0·6	1·1	1·2	1·4	—	—	4·8	3
%	4	6	13	23	25	29	—	—		
Sw	+	0·1	—	0·3	0·5	—	0·5	—	1·5	1
%	2	4	—	22	36	—	36	—		
Sb	—	—	—	—	—	—	—	—	—	—
%	—	—	—	—	—	—	—	—		—
Pw	+	—	—	—	—	—	—	—	+	+
%	100	—	—	—	—	—	—	—		
Ce	+	+	+	+	0·1	0·7	—	—	0·9	1
%	+	1	5	4	11	78	—	—		
Bw	—	—	+	0·3	1·0	2·5	12·5	0·9	17·2	11
%	—	—	+	2	6	14	73	5		
A	—	—	—	—	—	—	1·6	—	1·6	1
%	—	—	—	—	—	—	100	—		
Ew	+	+	+	0·1	—	—	0·4	—	0·6	+
%	2	4	4	24	—	—	66	—		
ASm	+	+	—	0·2	0·7	—	—	—	1·0	1
%	1	2	—	23	74	—	—	—		
By	+	0·1	0·2	0·9	2·9	6·6	14·9	28·4	54·0	34
%	+	+	+	2	5	12	28	53		
Ms	2·1	1·3	1·1	4·4	12·9	14·8	36·1	2·8	75·5	48
%	3	2	1	6	17	19	48	4		
Mr	+	0·1	+	+	—	0·2	—	—	0·4	+
%	4	17	11	9	—	59	—	—		
I	+	—	+	0·1	0·4	—	—	—	0·6	+
%	5	—	5	14	76	—	—	—		
Total									158·1	

Sp.	Total Volume per Acre									
	Diameter-class Groups								Total	% of Stand
	1	2	3	4–6	7–9	10–12	13–18	19+		
Fb	1	3	7	17	27	36	—	—	91	2
%	1	3	8	19	30	39	—	—		
Sw	+	+	—	6	11	—	18	—	36	1
%	+	1	—	16	31	—	51	—		
Sb	—	—	—	—	—	—	—	—	—	—
%	—	—	—	—	—	—	—	—		
Pw	+	—	—	—	—	—	—	—	+	+
%	100	—	—	—	—	—	—	—		
Ce	+	+	+	+	2	12	—	—	15	+
%	+	1	3	3	13	80	—	—		
Bw	—	—	1	8	26	63	323	22	443	11
%	—	—	+	2	6	14	73	5		
A	—	—	—	—	—	—	51	—	51	1
%	—	—	—	—	—	—	100	—		
Ew	+	+	+	2	—	—	11	—	13	+
%	+	2	2	16	—	—	80	—		
ASm	+	+	—	5	18	—	—	—	24	1
%	+	2	—	23	75	—	—	—		
By	+	1	2	13	67	182	457	900	1,622	41
%	+	+	+	1	4	11	28	56		
Ms	19	14	14	74	274	352	885	66	1,698	42
%	1	1	1	4	16	21	52	4		
Mr	+	1	+	1	—	5	—	—	7	+
%	2	9	7	8	—	74	—	—		
I	+	—	+	1	8	—	—	—	10	+
%	3	—	3	14	80	—	—	—		
Total									4,010	

APPENDIX C

Tables showing the Relation of Percentage Mortality of Fir and White Spruce to Certain Stand Variables for the Mississagi River and Montreal River Areas

TABLE 61

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area and Relative Height of Fir and Basal Area of White Spruce

Broad Cover Type: Softwood

Locality: Mississagi River

Basal Area Sw	Relative Height Fb	Basal Area of Fb 0–40 Mort. Fb	Mort. Sw	n[1]	Basal Area of Fb 41+ Mort. Fb	Mort. Sw	n
0–20	U	68	30	14	93	28	2
	I	93	66	44	98	74	29
	CD	94	93	4	100	72	11
21+	U	65	31	4	—	—	—
	I	94	61	12	98	77	16
	CD	—	—	—	96	72	2

[1] Number of sample plots.

Observations:
(1) Fir mortality increased with basal area of fir per acre.
(2) Fir mortality was not influenced by the quantity of white spruce per acre.
(3) In general, fir mortality increased with relative height of fir, although the difference was not marked between the intermediate and co-dominant categories.
(4) White spruce mortality was not influenced by the basal area of spruce per acre.
(5) White spruce mortality increased with the relative height of fir from understory to intermediate.

TABLE 62

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area and Relative Height of Fir and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Locality: Mississagi River

Basal Area Stand	Relative Height Fb	Basal Area of Fb 0–40 Mort. Fb	Mort. Sw	n	Basal Area of Fb 41+ Mort. Fb	Mort. Sw	n
0–150	U	—	—	—	—	—	—
	I	69	39	23	93	73	12
	CD	65	35	3	76	69	3
151+	U	70	60	7	—	—	—
	I	75	62	17	92	76	16
	CD	99	42	3	97	43	5

Observations:
(1) In general, fir mortality increased with quantities of fir per acre.
(2) In general, fir mortality increased with stand density.
(3) Fir mortality decreased with increased relative height of fir in low stand densities, and increased in high stand densities.

TABLE 63

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Percentage Content and Relative Height of Fir, and Basal area of the Whole Stand

Broad Cover Type: Mixedwood-hardwood (HS)

Locality: Mississagi River

Basal Area Stand	Relative Height Fb	Percentage of Fb 0–20 Mort. Fb	Sw	n	21+ Mort. Fb	Sw	n
0–150	U	68	39	3	67	11	4
	I	84	45	10	73	53	13
	CD	—	—	—	28	—	1
151+	U	—	—	—	57	37	1
	I	67	44	9	75	64	10
	CD	84	56	3	81	0	1

Observations:

(1) No consistent trend between fir mortality and percentage of fir.
(2) No consistent trend between fir mortality and total stand density.
(3) Fir mortality increased with relative height of fir.

TABLE 64

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area and Relative Height of Fir and Basal Area of White Spruce

Broad Cover Type: Softwood

Locality: Montreal River

Basal Area Sw	Relative Height Fb	Basal Area of Fb 0–40 Mort. Fb	Sw	n	41–80 Mort. Fb	Sw	n	81+ Mort. Fb	Sw	n
0–20	U	48	0	5	67	12	2	—	—	—
	I	50	7	18	79	23	8	99	100	2
	CD	54	23	5	79	40	11	96	15	4
21+	U	—	—	—	98	71	1	—	—	—
	I	73	63	1	86	66	3	—	—	—
	CD	44	46	4	87	72	9	94	32	2

Observations:

(1) Fir mortality increased with basal area of fir per acre.
(2) Fir mortality increased with basal area of white spruce per acre.
(3) Fir mortality was not related to the relative height of fir.
(4) White spruce mortality increased with basal area of white spruce per acre.
(5) White spruce mortality increased with basal area of fir, up to fir concentrations of about 80 sq. ft. per acre (also see Fig. 14).

TABLE 65

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Basal Area and Relative Height of Fir, and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-softwood (SH)

Locality: Montreal River

Basal Area Stand	Relative Height Fb	Basal Area of Fb: 0–40, Mort. Fb	0–40, Mort. Sw	0–40, n	41+, Mort. Fb	41+, Mort. Sw	41+, n
0–200	U	51	0	2	—	—	—
	I	57	35	7	72	56	7
	CD	51	43	13	78	86	5
201+	U	48	1	2	—	—	—
	I	43	20	6	66	33	7
	CD	48	46	5	61	36	15

Observations:

(1) Fir mortality increased with basal area of fir per acre.
(2) Fir mortality decreased with increased total stand density.
(3) Fir mortality was not affected by the relative height of fir.

TABLE 66

Percentage Mortality of Balsam Fir and White Spruce in Plots Segregated on the Basis of Percentage Content and Relative Height of Fir, and Basal Area of the Whole Stand

Broad Cover Type: Mixedwood-hardwood (HS)

Locality: Montreal River

Basal Area Stand	Relative Height Fb	Percentage of Fb: 0–20, Mort. Fb	0–20, Mort. Sw	0–20, n	21+, Mort. Fb	21+, Mort. Sw	21+, n
0–200	U	0	0	1	—	—	—
	I	44	26	8	76	3	7
	CD	64	40	6	78	28	6
201+	U	—	—	—	—	—	—
	I	38	32	4	42	0	1
	CD	48	7	9	55	49	5

Observations:

(1) Fir mortality increased with percentage of fir in the stand.
(2) Fir mortality decreased with increased total stand density.
(3) Fir mortality increased with relative height of fir.

APPENDIX D

Tables showing the Percentage Mortality of Fir and White Spruce by Cover Types for the Mississagi River and Montreal River Areas

TABLE 67

Percentage Mortality of Balsam Fir and White Spruce in Cover Types Grouped by the Predominant Softwood Component and Within Broad Limits of Fir Content for Both the Softwood and Mixedwood Broad Types

Locality: Mississagi River

B.A. Fb	SFS				SP				SC				SM			
	Mort. Fb	Mort. Sw	B.A. Fb	n[1]	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	92	41	17	25	92	61	23	46	70	2	20	3	83	73	19	6
41+	98	73	82	34	98	76	56	19	100	97	42	1	98	79	59	5
Average	97	63	56	59	94	64	32	65	86	62	27	4	94	77	38	11
	(1)[2]				(2)				(4)				(3)			

B.A. Fb	SH_{FS}				SH_P				SH_C				SH_M			
	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	74	52	25	25	66	33	22	18	97	82	22	7	88	0	26	3
41+	92	69	66	31	96	40	51	4	92	—	41	1	—	—	—	—
Average	92	70	55	56	75	33	26	22	97	82	24	8	88	0	26	3
	(2)				(4)				(1)				(3)			

B.A. Fb	HS_{FS}				HS_P				HS_C				HS_M			
	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
Average	71	52	37	47	72	26	13	6	67	0	11	2	45	0	6	1
	(2)				(1)				(3)				(4)			

[1] Number of sample plots.
[2] The numerical sequence of each panel is according to the degree of fir mortality in the "average" row.

TABLE 68

Relation of Percentage Mortality of Fir and White Spruce to Percentage Hardwood in Stands, by comparing Detailed Cover Types wherein the Softwood Component Species and the Variables found to affect Fir Mortality are controlled within Broad Limits

Locality: Mississagi River

Controlled Variables		S_1FS					S_2FS					SHI_{FS}					HSI_{FS}				
B.A. Fb	Ht. Fb	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n
0–40	I	95	41	19	10	12	92	69	24	16	4	74	49	25	19	20	66	49	27	15	20
41+	I	97	75	70	20	18	99	72	88	20	9	92	76	64	13	19	74	58	55	7	7
	CD	99	70	95	18	6	100	—	91	—	1	84	78	52	14	4	81	0	44	1	1
		S_1P					S_2P					SHI_P					HSI_P				
0–40	I	94	80	24	6	19	93	65	28	14	15	68	29	23	12	9	53	23	22	12	2
41+	I	99	89	59	9	10	99	66	50	7	4	97	31	52	2	3	—	—	—	—	—

TABLE 69

Percentage Mortality of Balsam Fir and White Spruce by Broad Cover Types, Controlling within Broad Limits in Section (1) those Variables Shown to Affect Fir Mortality in all Broad Cover Types, and Giving Successively Broader Groupings of the Data in Sections (1) to (4) (see Table 49)

Locality: Mississagi River

B.A. Fb	Rel. Ht. Fb	S_1				S_2				SH				HS				H_1				H_2			
		Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	U	75	17	7	12	68	48	16	7	70	60	21	7	68	39	13	3	68	62	22	5	41	0	3	4
(1)	I	94	66	23	34	91	63	27	22	72	50	23	40	70	48	22	32	59	47	25	10	45	0	10	4
	CD	81	20	18	4	100	100	19	1	92	51	26	6	84	60	29	3	87	23	22	3	—	—	—	—
41+	U	—	—	—	—	95	28	44	1	—	—	—	—	65	18	47	6	—	—	—	—	—	—	—	—
	I	98	78	63	32	99	71	73	14	92	75	62	28	77	58	57	10	—	—	—	—	—	—	—	—
	CD	99	73	89	8	100	59	81	4	93	50	70	8	65	0	48	2	—	—	—	—	—	—	—	—
0–40 (2)	Tot.	92	51	20	50	89	60	25	30	76	51	23	53	71	50	22	38	66	42	24	18	44	0	6	8
41+	Tot.	98	77	70	40	98	66	69	19	92	68	64	36	72	45	53	18	—	—	—	—	—	—	—	—
All variables combined (3)		96	66	40	90	95	62	41	49	87	58	40	89	71	49	33	56	66	42	24	18	44	0	6	8
		S								SH				HS				H							
All variables combined (4)		96	64	40	139					87	58	40	89	71	49	33	56	64	39	18	26				

TABLE 70

Percentage Mortality of Balsam Fir and White Spruce in Cover Types Grouped by the Predominant Softwood Component and Within Broad Limits of Fir Content for Both the Softwood and Mixedwood Broad Types

Locality: Montreal River

B.A. Fb	SFS				SP				SC				SM			
	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	50	17	24	13	23	0	33	2	54	44	25	12	55	48	28	5
41+	92	64	75	26	87	68	62	3	69	11	58	9	71	43	47	4
Average	88	59	61	39	76	48	55	5	63	31	38	21	64	46	36	9
	(1)[1]				(2)				(4)				(3)			

B.A. Fb	SH_{FS}				SH_P				SH_C				SH_M			
	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	57	46	27	14	—	—	—	—	43	31	24	19	52	0	38	1
41+	67	42	68	24	79	0	56	1	51	63	43	5	71	31	57	5
Average	65	44	51	38	79	0	56	1	46	36	29	24	68	17	52	6
	(3)				(1)				(4)				(2)			

B.A. Fb	HS_{FS}				HS_P				HS_C			
	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
Average	63	26	36	34	0	0	10	1	57	36	23	12
	(1)				(3)				(2)			

[1] The numerical sequence of each panel is according to the degree of fir mortality in the "average" row.

TABLE 71

Relation of Percentage Mortality of Fir and White Spruce to Percentage Hardwood in Stands, by Comparing Detailed Cover Types wherein the Softwood Component Species and the Basal Area of Fir are Controlled within Broad Limits

Locality: Montreal River

B.A. Fb	S_1FS					S_2FS					SHI_{FS}					HSI_{FS}				
	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n	Mort. Fb	Mort. Sw	B.A. Fb	B.A. Sw	n
0–40	57	0	25	+	8	39	17	30	+	5	76	22	29	17	6	57	40	34	31	5
41+	94	69	76	27	16	87	52	71	24	10	71	52	70	23	19	71	2	59	7	8
Average	91	69	65	20	24	81	43	55	22	15	72	44	58	21	25	67	31	49	16	13

TABLE 72

Percentage Mortality of Balsam Fir and White Spruce by Broad Cover Types, Controlling Within Broad Limits the Variable Shown to Affect Fir Mortality in all Cover Types

Locality: Montreal River

B.A. Fb	S_1				S_2				SH				HS				H_1				H_2			
	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n	Mort. Fb	Mort. Sw	B.A. Fb	n
0–40	54	24	21	13	49	34	28	19	50	38	26	34	57	26	22	33	49	43	16	20	47	30	6	30
41+	93	68	74	22	79	42	63	20	67	42	62	35	65	24	57	14	—	—	—	—	—	—	—	—
Average	89	69	60	35	70	38	45	39	62	40	44	69	62	26	32	47	49	43	16	20	47	30	6	30
	S								SH				HS				H							
Average	80	53	52	74					62	40	44	69	62	26	32	47	48	40	11	50				

APPENDIX E

List of the More Important Recommendations made by Various Authors for Reducing the Susceptibility and Vulnerability of Fir-Spruce Stands

Reference no.	Author	Recommendations
3	Balch (1946)	Accurately determine areas where considerable stands of mature balsam-spruce occur.
		Make these areas fully accessible by an adequate system of permanent forest roads.
		Direct cutting into these areas as rapidly as possible, in preference to areas where spruce or younger stands predominate.
		Design methods of cutting to achieve the objects mentioned above. Over-mature defective balsam should be cut to the limit of practicability. The cutting of immature spruce should be avoided.
		Consider the future management of areas where there are large quantities of young balsam fir which will constitute a budworm hazard as it matures.
7	Craighead (1924)	Develop stands in blocks of different age classes.
		Clear cut fir to smallest diameter limit.
		Retain white and black spruce seed trees to increase the proportion of these species in the succeeding stands.
		Utilize fir on a short rotation.
		Utilize hardwoods to make possible proper management of mixed softwood-hardwood second growth.
		On thin soils and poorer sites, grow budworm-immune trees such as pines.
8	Craighead (1925)	Recommendations were specific only to the Maritime area. Main idea is to cut selectively, promoting thrifty stands and favouring spruce.
13	Graham (1939)	Prevent development of susceptible stands on extensive areas at any one time.
		Divide stand into 40-acre units, and develop maximum variation in age and composition among adjacent units. Prevent a contiguous area from reaching maturity at the same time.
14	Graham and Orr (1940)	On tracts of land where fir is to be one of the major crop species, subdivide the land into small working units.
		Through cultural methods, prevent the maturity of balsam fir over extensive areas; keep the fir uneven-aged.
		Where other species are present in quantity, favour them at the expense of fir. Even though white birch and poplar may have little commercial value in an area, they have a very important value in terms of protection to fir.
15	de Gryse (1944)	Remove mature and over-mature balsam stands.
		Utilize, on short rotation, younger and more vigorous balsam stands.
		Foster regeneration of better species, particularly spruce.

Reference no.	Author	Recommendations
21	McLintock (1947)	Use principle of partial cutting. Cut stands first which have much mature and over-mature fir, in preference to stands where the percentage of spruce is high or where fir is young and vigorous. Old unmerchantable fir left after logging should be cut as a sanitation measure. Decrease proportion of balsam to spruce by cutting to encourage establishment of spruce. Use short cutting cycle—about 20 years. This saves losses from decay and windthrow.
22	McLintock (1948)	A single-tree selection system on a short rotation (up to 25 years). Selection of trees for cutting is based on vigour, which takes into account lateral and terminal growth, and general crown development. Trees with lower vigour are cut first.
24	McLintock and Westveld (1946)	In cutting operations, remove over-mature and defective balsam fir, regardless of the amount of merchantable wood. This step is believed possible at no undue cost to the operator.

The main recommendations made by Westveld (35, 36, 37) are summarized in the following tabular form, which is taken directly from a short paper by Westveld and MacAloney (38).

Cutting Practices to Prevent Budworm Damage

Selection Cutting

Types of Stands	Immediate Objectives	Guiding Principles	Cutting Guides
Young, merchantable even, or uneven-aged spruce and balsam fir in varying mixtures; other conifers in admixture, hardwood admixtures in varying amounts.	(1) Increase spruce representation. (2) Promote high thrift. (3) Promote rapid wood production. (4) Assure reproduction. (5) Maintain windfirm stands.	Favor spruce over fir. Light but frequent cuts. Retain well distributed, healthy, potentially fast-growing trees. Restrict cut to 40% of volume. In no event remove more than 60%.	*Stands with high spruce content.* Cut spruce 14 inches D.B.H. and larger plus poor risk specimens below this diameter. Cut balsam fir down to 6 inches D.B.H. *Stands with low spruce content.* Save all vigourous good-risk spruce. Also reserve healthy, vigorous 6, 7, 8 and 9-inch balsam firs in sufficient number to preclude windfall and assure rapid increment.

Clear Cutting

Mature and over-mature even-aged dominantly balsam fir stands.	(1) Forestall serious loss from budworm, windthrow, and defect	Stand improvement measures.	Cut all merchantable trees.
Overmature even-aged spruce stands.	(2) Stimulate rapid growth of advance spruce-fir reproduction.		